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FILM LIGHTING USING METAL-HALIDE LAMPS: some operating conditions giving freedom from picture luminance fluctuations

E.W. Taylor, M.A.(Cantab.), C.Eng., M.I.E.E.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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E.W. Taylor, M.A.(Cantab.), C.Eng., M.I.E.E.

Summary

Film and display parameters required to specify the operating conditions and describe exposure variation and luminance fluctuation effects are defined. Theoretical relationships between camera frame frequency and shutter angle, and lamp supply frequency and intensity ripple characteristics, such that picture luminance fluctuations due to the presence of this ripple component are not perceptible, are presented in a series of charts and formulae. Camera shutter angles from 80° to 300°, camera frame frequencies of 24 Hz and 25 Hz, and lamp supply frequencies in the range 43 Hz to 67 Hz are included.

Issued under the authority of

G D Monteath

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

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1. Introduction

Theoretical relationships governing the amount of exposure variation, and therefore the visibility of picture luminance fluctuations, when discharge lamps are used for scene lighting in motion picture film work have been described in previous reports.[1,2,3] The present report is based on this theoretical work and presents practical limiting relationships which will ensure that picture luminance fluctuations remain imperceptible. These practical limits refer to cameras operating at either 24 or 25 frames per second, with the film replayed at the same speed as it was exposed (i.e. slow-motion or accelerated-motion conditions are not included). A lamp supply frequency range of 43-67 Hz is covered. The calculations leading to these limits are based on the assumption that the intensity "ripple" component (see Fig. 1, Section 2.1.) is sinusoidal in character: this is not strictly true in practice, but check calculations using ripple waveforms from practical lamps[2a] show that the errors involved in making this assumption are reasonably small and are in any case in a direction which decreases the visibility of picture luminance fluctuations. The calculations also involve the approximation that $\sin x = x$ when x is small:[3a,3b] this approximation is valid for the operating conditions described in this report, any inaccuracy arising from the use of this approximation again being such as to decrease the visibility of picture luminance fluctuations.

2. Definitions

2.1. Lamp parameters

Lamp supply frequency (symbol f_s): the frequency of the alternating supply to the lamp.

Intensity ripple component: the variation in the intensity of light from the lamp at a frequency of twice that of the supply.

Ripple ratio (symbol p): the ratio of the minimum and maximum light intensity values. If alternate maxima differ in value, the mean of the two maximum values is taken. Thus if (see Fig. 1)

$$I_{mm} = \frac{I_{max1} + I_{max2}}{2}$$

Then

$$p = \frac{I_{min}}{I_{mm}} \qquad \ldots\ldots (1)$$

Exposure variation and picture luminance fluctuation components (see Section 2.3.) due to the presence of the intensity ripple are termed "principal" components.

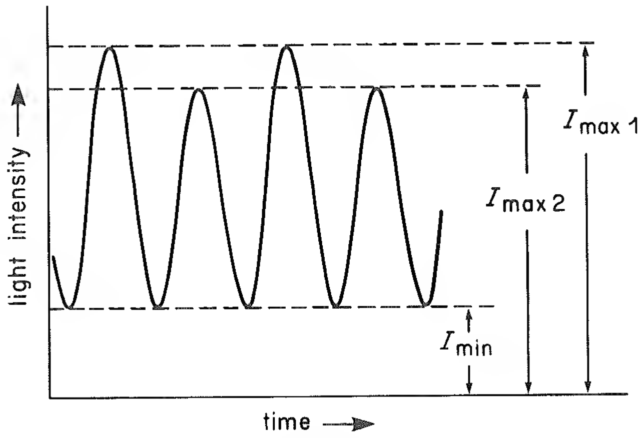

Fig. 1 - Illustration of variation in light intensity from a discharge lamp showing ripple asymmetry

Asymmetry ratio (symbol p'): the ratio of the smaller maximum light intensity value to that of the larger value (see Fig. 1). Thus

$$p' = \frac{I_{max2}}{I_{max1}} \qquad \ldots\ldots (2)$$

Exposure variation and picture luminance fluctuation components (see Section 2.3.) due to the presence of ripple asymmetry are termed "asymmetry" components.

Ripple period (symbol t_r): the time interval occupied by one cycle* of ripple waveform. Note that because of the reciprocal relation between period and frequency, and the fact that ripple frequency is twice that of the lamp supply frequency,

$$t_r = \frac{1}{2f_s} \qquad \ldots\ldots (3)$$

2.2. Camera parameters

Camera frame frequency (symbol f_c): the number of frames per second exposed by the camera.

* In this context, one excursion of light intensity from minimum to either the smaller or the larger maximum and back again to minimum.

Camera frame period (symbol t_c): the time interval occupied by one cycle of operation of the camera (i.e. the reciprocal of the camera frame frequency).

Camera shutter angle (symbol θ): the fraction of a complete cycle of operation of the camera during which the shutter is open and the film is being exposed, expressed in angular measure taking a complete operating cycle as 360°. With a simple rotating disc shutter rotating once per operating cycle, it is the angle included in the "open" sector of the shutter.

Exposure interval (symbol t_e): the time interval during which the film is exposed. The exposure interval is given by

$$t_e = \frac{\theta}{360} t_c$$

or

$$t_e = \frac{\theta}{360.\ f_c} \qquad \ldots\ldots (4)$$

where θ is expressed in degrees.

The exposure interval may be expressed in terms of the intensity ripple component by the relationship

$$t_e = t_r (N + Q) \qquad \ldots\ldots (5)$$

where N is the nearest whole number to the number of ripple cycles in the exposure interval

and Q is the fractional part of a ripple cycle by which the exposure interval differs from a whole number of such cycles.

2.3. Film and display parameters

Ratios of maximum and minimum values of exposure (symbols M_E (principal component) and M'_E (asymmetry component)): measures of the amount of exposure variation produced by the use of discharge lamps in film lighting. The magnitudes of these quantities depend on the values of N and Q (see Equation 5), the value* of ripple ratio (p in Equation 1) and in the case of the asymmetry component the value of asymmetry ratio (p' in Equation 2). Reference should be made to earlier work for detailed relationships:[2b,2c,3a,3b,3c] for present purposes these relationships can be written in the form

$$M_E = \text{fn}\,(N, Q, p) \qquad \ldots\ldots (6)$$

$$M'_E = \text{fn}\,(N, Q, p, p') \qquad \ldots\ldots (7)$$

* and, strictly speaking, the waveform of the ripple component. In this Report each cycle of ripple waveform is assumed to be a sinusoid (see Section 1).

where fn ( ) indicates a function of the variables in the brackets without implying any specific formulation of the function.

Exposure fluctuation ratio (symbols R_E (principal component) and R'_E (asymmetry component)): a more convenient measure of exposure variation than the value of M_E. For the principal component of exposure variation, the ratio is defined by the relationship

$$R_E = 20 \log_{10} \left(\frac{2 + g_E}{2g_E} \right)$$

$$= 20 \log_{10} \frac{1}{g_E} \quad \text{if } g_E \ll 1 \qquad \ldots\ldots (8)$$

where

$$g_E = M_E - 1$$

The corresponding quantity R'_E for the asymmetry component of exposure variation is defined in relation to M'_E in the same way.

Limiting values of exposure fluctuation ratio (symbol $R_{E(Lim)}$): values of exposure fluctuation ratio which ensure the imperceptibility of the resulting picture luminance fluctuations, without unnecessarily severe limitations on their magnitude. These values have been determined in previous work[1a] and are reproduced in Fig. 2. As can be seen, these values are strongly frequency-dependent (see below). They apply equally to the principal and asymmetry exposure variation components.

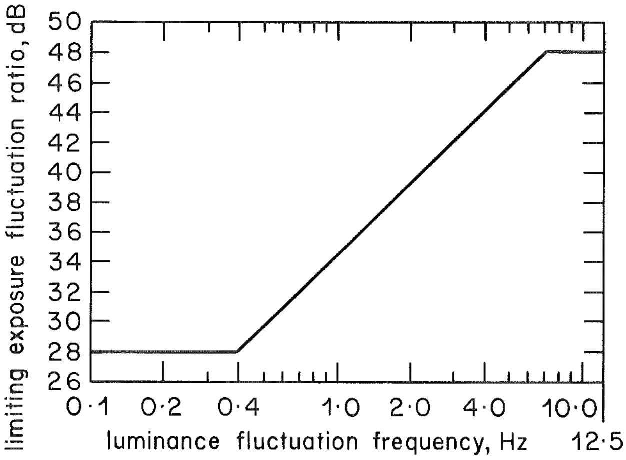

Fig. 2 - Relation between limiting exposure fluctuation ratio ($R_{E(Lim)}$) and luminance fluctuation frequency (f_L)

Picture luminance fluctuation frequency (symbols f_L (principal component) and f'_L (asymmetry component)): the frequency of the fluctuation of displayed or projected picture luminance. In general, the picture luminance fluctuation frequency for the principal component is given by

$$f_L = \frac{f_p}{f_c} \, |2f_s - mf_c| \qquad \ldots\ldots (9)$$

where f_p is the replay frame frequency (defined in the same terms as the camera frame frequency: see Section 2.2.),

and m is the nearest whole number to the number of ripple cycles in the camera frame period.*

In the present context $f_p = f_c$ (see Section 1) and Equation 9 reduces to

$$f_L = |2f_s - mf_c| \qquad \ldots\ldots (10)$$

The frequency of the asymmetry component of luminance fluctuation (f'_L) is then related to the frequency of the principal component (f_L) by the following expressions:—

$$f'_L = f_L/2 \qquad \text{if } m \text{ is even}$$

$$f'_L = \tfrac{1}{2}(f_c - f_L) \qquad \text{if } m \text{ is odd} \qquad \ldots\ldots (11)$$

3. Supply frequency limit charts

3.1. Derivation of charts

The derivation of the supply frequency limit charts is based on considerations of intensity ripple magnitude without regard to asymmetry of the ripple waveform and therefore involves only the principal exposure variation component. The magnitude (M_E) of this component depends (see Equation 6) on the values of N, Q and p. The values of N and Q depend in turn on the exposure interval t_e and ripple period t_r (see Equation 5). Furthermore, the exposure interval depends on the camera frame frequency f_c and shutter angle θ (see Equation 4) while the ripple period depends on the lamp supply frequency f_s (see Equation 3). Thus Equation 6 may be re-written**

$$M_E = \text{fn}\,(f_c, \theta, f_s, p) \qquad \ldots\ldots (12)$$

Hence, for given values of camera frame frequency, shutter angle, and ripple ratio,

$$M_E = \text{fn}\,(f_s) \qquad \ldots\ldots (13)$$

As an example, Fig. 3 shows a relationship between M_E and f_s when f_c = 25 Hz, θ = 172° and the value of p was as measured from a commercially-available metal-halide lamp. Using Equation 8 it is possible to express the exposure variation magnitude in terms of exposure fluctuation

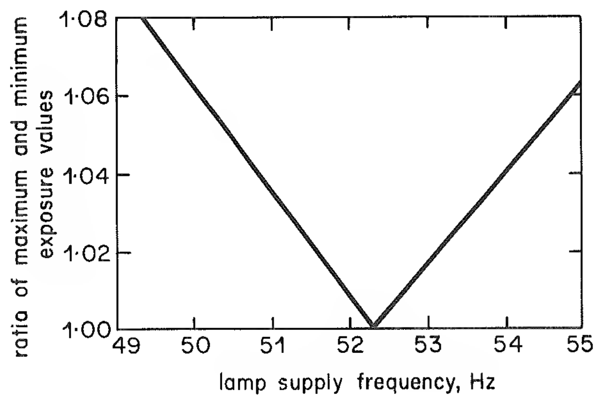

Fig. 3 - Example of relationship between the ratio of maximum and minimum exposure values (M_E) and the lamp supply frequency (f_s)

ratio (R_E) rather than in terms of M_E: thus

$$R_E = \text{fn}\,(f_s) \qquad \ldots\ldots (14)$$

Turning now to the limiting values of exposure fluctuation ratio ($R_{E(Lim)}$), it is evident from Fig. 2 that

$$R_{E(Lim)} = \text{fn}\,(f_L) \qquad \ldots\ldots (15)$$

Since f_L depends on f_p, f_c and f_s (see Equation 9), Equation 15 may be written

$$R_{E(Lim)} = \text{fn}\,(f_p, f_c, f_s) \qquad \ldots\ldots (16)$$

and if $f_p = f_c$ (see Section 1) and only a particular value of f_c is considered, Equation 16 becomes

$$R_{E(Lim)} = \text{fn}\,(f_s) \qquad \ldots\ldots (17)$$

It can now be seen that Equations 14 and 17 are directly comparable: thus the variation of the practical exposure fluctuation ratio with lamp supply frequency (Equation 14) and the variation of the limiting exposure fluctuation ratio with lamp supply frequency (Equation 17) may be plotted using the same axes. This is shown in Fig. 4, the full line referring to Equation 17 and the dotted line to Equation 14. Note that the same value of f_L can arise from different lamp supply frequencies, as the term within the modulus sign of Equation 9 (or 10) can be either positive or negative, and the integer m can adopt different values: this accounts for the periodic nature of the full line in Fig. 4. Note also that this figure only applies to specific values of camera frame frequency, camera shutter angle and ripple ratio. If the dotted line in Fig. 4 lies above the full line,* the amount of exposure variation obtained in practice is less than the limiting value and the picture luminance fluctuations are consequently imperceptible. The converse applies if the dotted line

* m is not an independent variable in Equation 9 as it is itself determined by the relation between camera frame frequency and lamp supply frequency.

** See note following Equation 7: the actual forms of the functions in Equations 12-17 may differ from each other and from the form in Equation 6.

* remembering that a higher value of exposure fluctuation ratio implies a smaller magnitude of exposure variation.

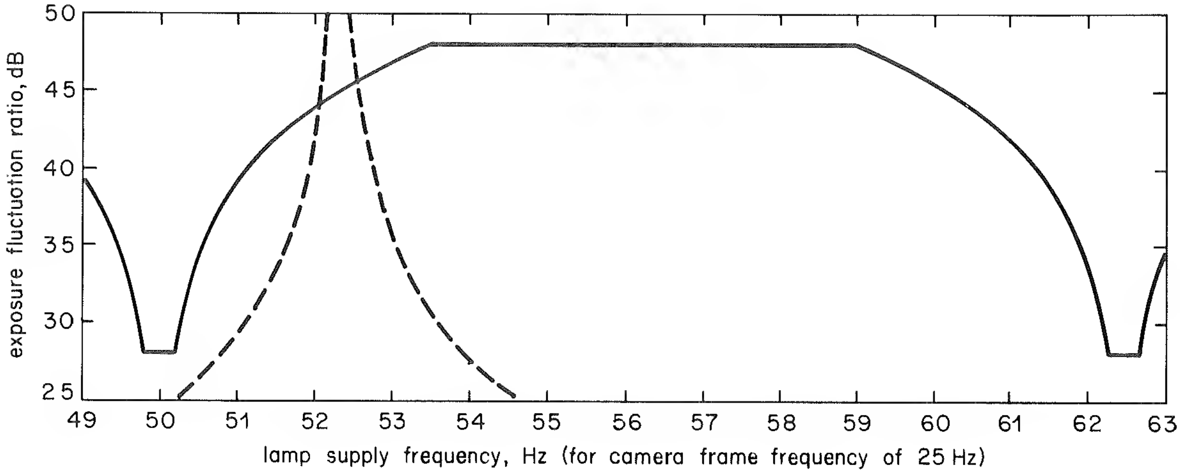

Fig. 4 - Example of the variation with frequency of limiting ($R_{E(Lim)}$) and practical (R_E) exposure fluctuation ratios

Limiting (see Fig. 2)
Practical (see Fig. 3)

lies below the full line in Fig. 4, and picture luminance fluctuations may then be perceptible. Thus the lamp supply frequencies corresponding to the points where the full and dotted lines intersect represent "safe" limits: operation within these limits will ensure that picture luminance fluctuations remain imperceptible.

The effect of altering the camera shutter angle can now be discussed. Previous work[2d] has shown that the principal effect of this alteration is to cause a horizontal translation of the dotted curve in Fig. 4: the shape of the curve also changes slightly but the effect of this change of shape is small compared with the effect of the sideways translation. Thus as the shutter angle is changed the points of intersection of the full and dotted lines also change, giving corresponding changes in the safe lamp supply frequency limits. The situation can now occur where there are four such points of intersection (Fig. 5) giving two ranges of safe lamp supply frequency.

It is now possible to plot out a "contour" of safe lamp supply frequency values, within which no perceptible luminance fluctuations will occur, as a function of camera shutter angle (θ). Such a plot will still refer to a particular camera frame frequency and value of ripple ratio. Figs. 6 and 7 show such plots for camera frame frequencies of 24 Hz and 25 Hz respectively, and for one value of ripple ratio. The points of intersection of a vertical line (corresponding to a particular value of θ) with the contour indicate on the ordinate axis the safe lamp supply frequency limits. The regions where the two branches of the contour broaden out to include a greater range of safe lamp supply frequencies correspond to the situation where the dotted-line curve in Fig. 4 is centred on a lamp supply frequency near which the full-line curve is at a minimum. Vertical lines passing through the "wings" of these broadened areas also intersect the contours again, either above or below the broadened areas, indicating two ranges of safe lamp supply frequency arising as shown

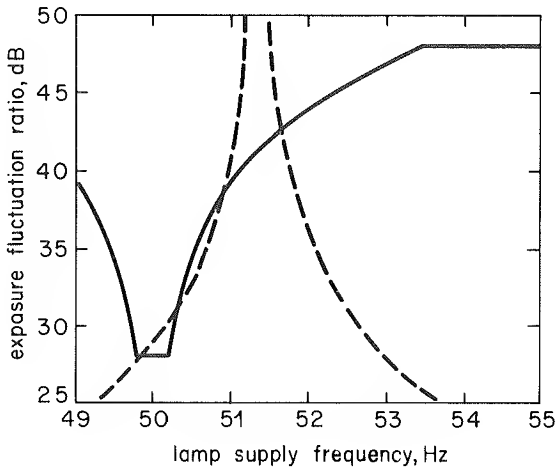

Fig. 5 - Illustration of relation between limiting ($R_{E(Lim)}$) and practical (R_E) exposure fluctuation ratios giving two ranges of "safe" lamp supply frequencies

Limiting
Practical

in Fig. 5. The values of the integer m shown in Figs. 6 and 7 are those which should be used in Equation 10 when calculating the luminance fluctuation frequency (f_L) corresponding to a particular lamp supply frequency (f_s). The horizontal lines against which the values of m appear indicate, in fact, the values of f_s for which $f_L = 0$. For other values of f_s, the value of m shown against the nearest such horizontal line in Fig. 6 or 7 should be taken when using Equation 10.

Since each complete contour "band" in Figs. 6 and 7 corresponds (as shown) to one value of the integer N in

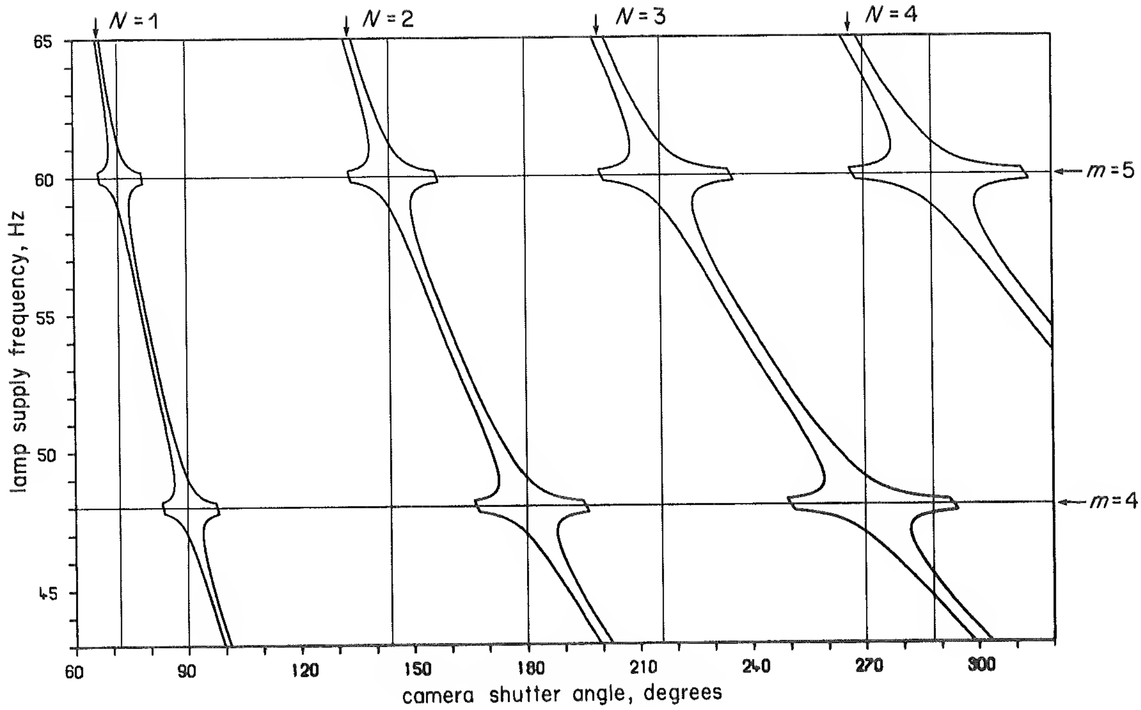

Fig. 6 - Camera frame frequency of 24 Hz

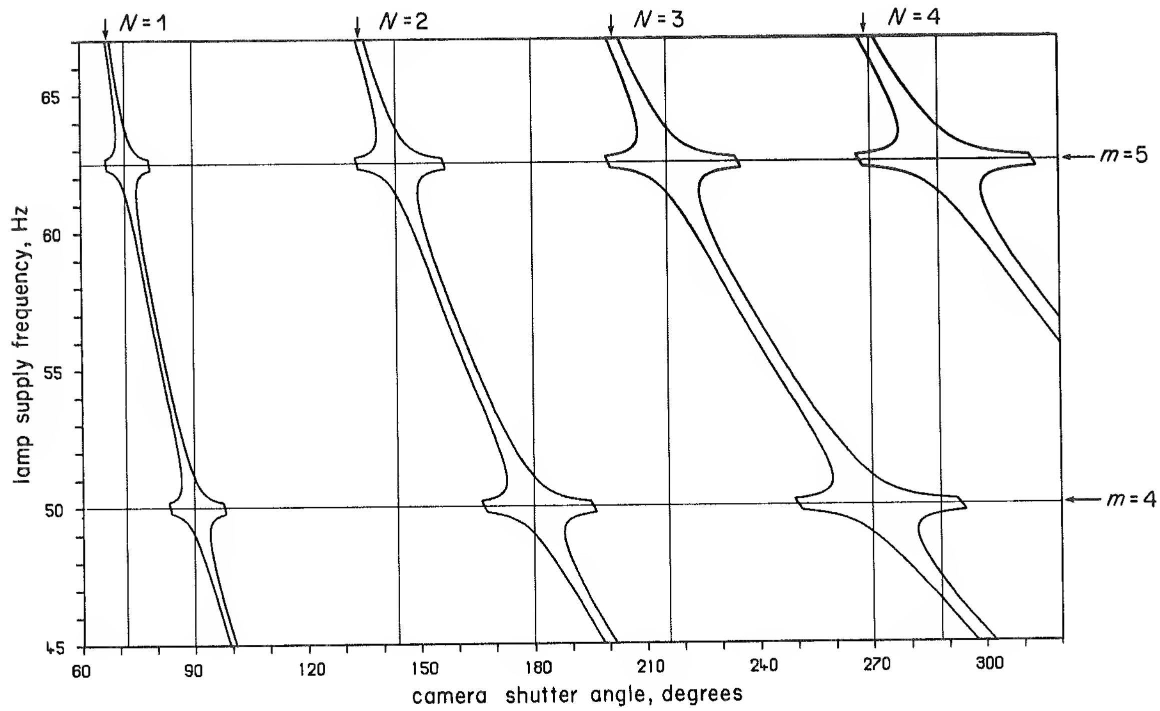

Fig. 7 - Camera frame frequency of 25 Hz

Figs. 6 and 7 - Contours of safe lamp supply frequencies for one ripple ratio value

m is the nearest whole number to the number of ripple cycles in the camera frame period

N is the nearest whole number to the number of ripple cycles in the exposure interval

Equation 5, each broadened area of a contour band is uniquely characterized by particular values of m and N. Operation within these broadened areas is clearly to be preferred, since the lamp supply frequency tolerances are considerably relaxed in these cases: these areas are therefore shown in greater detail in charts 1-10 (Section 3.2.). Each of these charts is identified by the values of m, N and the relevant camera frame frequency f_c.

The effect of changing the ripple ratio value is to cause a vertical translation of the dotted curve in Fig. 4. An increase of ripple ratio causes an upwards translation and it can be seen that this produces (as would be expected) an increase in the range of safe lamp supply frequencies. The detailed contour charts show contours for values of ripple ratio in steps of 0·1 over a range $p = 0$ (innermost contour) to $p = 0{\cdot}6$ (outermost contour). As the contours become rather crowded as the luminance fluctuation frequency increases, alternate contours are suppressed for lamp supply frequencies differing by 2 Hz from that giving "zero" fluctuation frequency as given by Equation 10.

3.2. Charts for ripple ratios in the range 0-0·6

The derivation and use of the supply frequency limit charts has been described in detail in Section 3.1. A summary of the method of use of the charts follows:—

1) Select the appropriate chart for the required camera frame frequency and shutter angle (see Table 1). If the required shutter angle does not fall in the range of any of these charts refer to Section 3.5.

2) Select the appropriate contour for the required ripple ratio, interpolating between the contours shown on the chart if necessary. Note that the contours are for ripple ratios of 0 to 0·6 in steps of 0·1, the innermost contour being for a ripple ratio of zero.

3) Draw a vertical line upwards from the appropriate camera shutter angle calibration.

4) Draw horizontal lines from the points of intersection of this vertical line with the two branches of the ripple ratio contour, to intersect the lamp supply frequency axis.

5) Safe lamp supply frequencies lie within the values, indicated by the horizontal lines drawn in Step 4, for which the vertical line drawn in Step 3 lies among contours of lower ripple ratio value than the value used in Step 2. Reference should be made to Section 4 for the effect of ripple asymmetry.

TABLE 1

Supply frequency limit charts: ripple ratios 0-0·6

Chart No.	Camera frame frequency (Hz)	Shutter angle range (degrees)
1	24	83-99
2	24	134-155
3	24	165-199
4	24	202-233
5	24	247-299
6	25	83-99
7	25	136-154
8	25	165-198
9	25	204-230
10	25	248-297

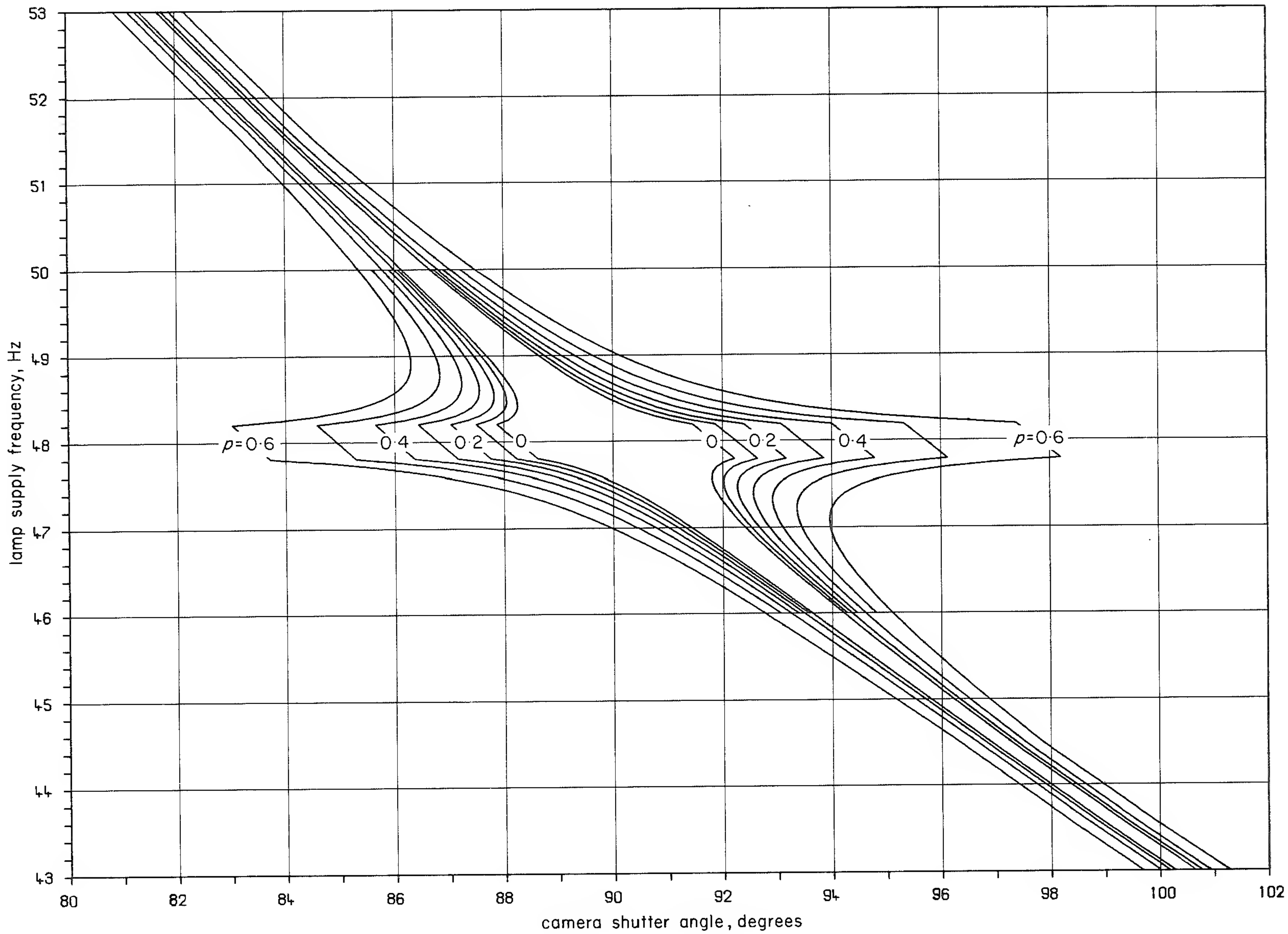

Chart 1 - Lamp supply frequency limits

$m = 4$ $N = 1$ camera frame frequency = 24 Hz (Ripple asymmetry limits : see chart 23)

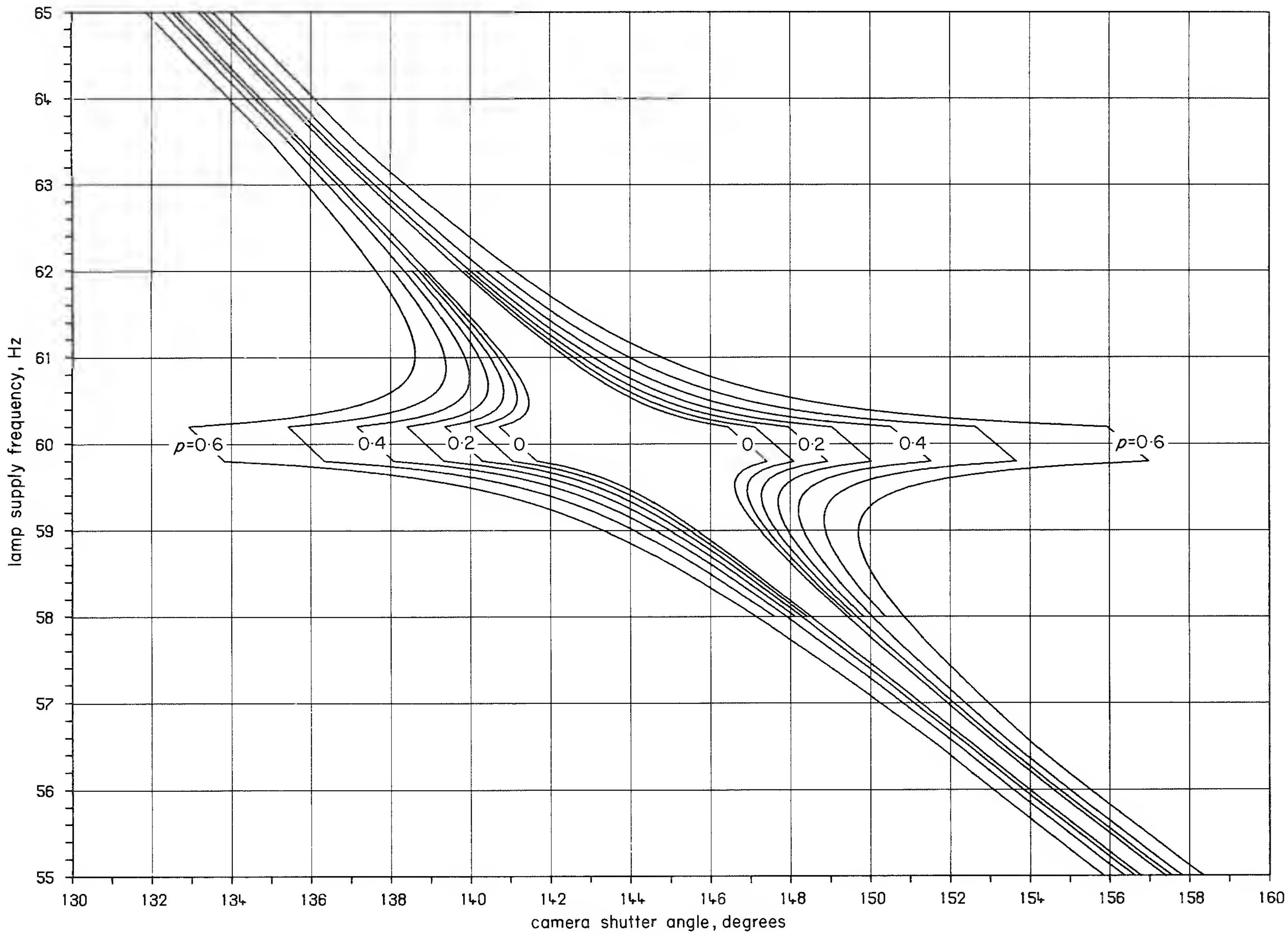

Chart 2 - Lamp supply frequency limits

m = 5 N = 2 camera frame frequency = 24 Hz (Ripple asymmetry limits : see chart 25)

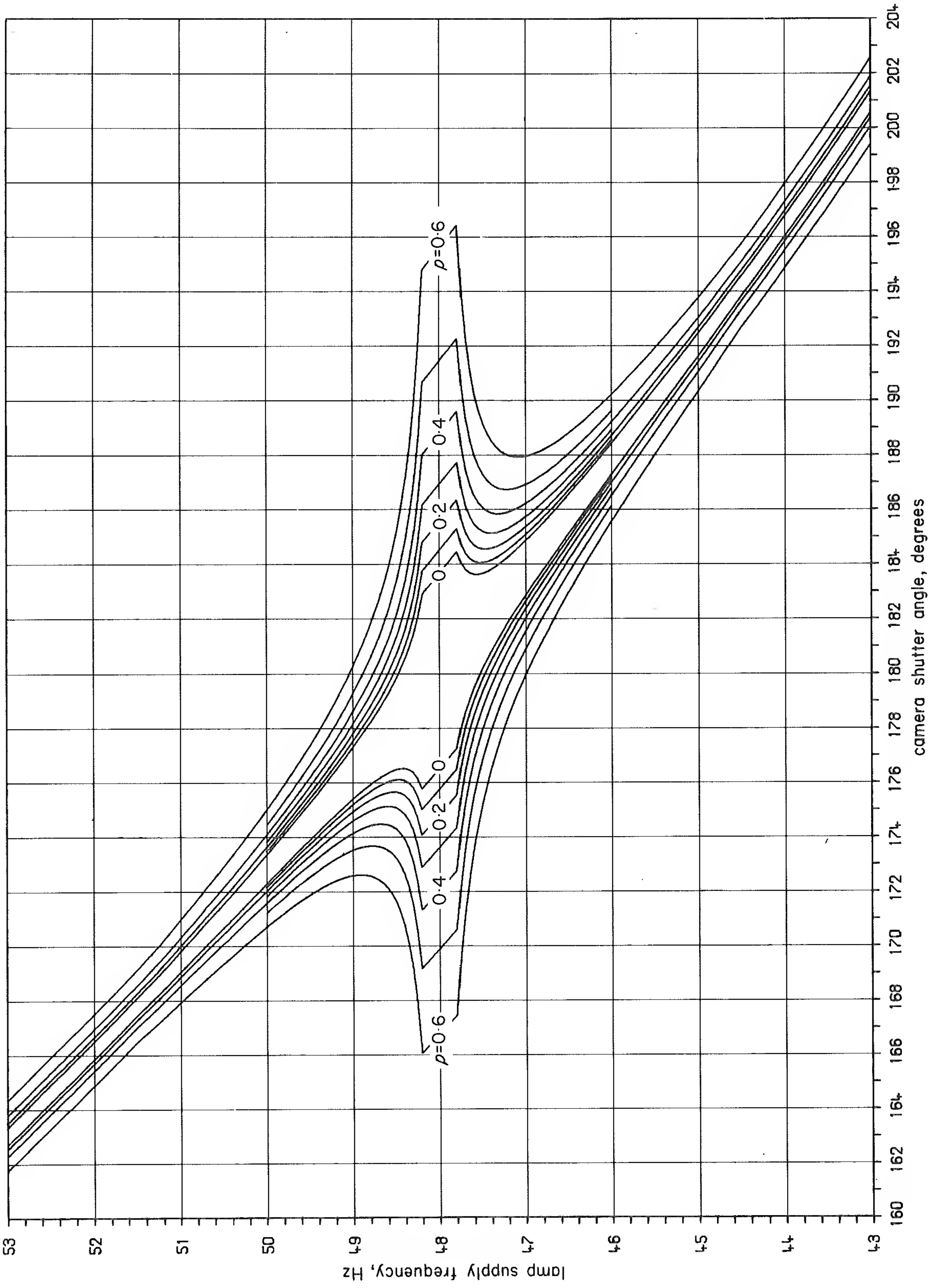

Chart 3 - Lamp supply frequency limits

$m = 4$ $N = 2$ camera frame frequency = 24 Hz (Ripple asymmetry not significant)

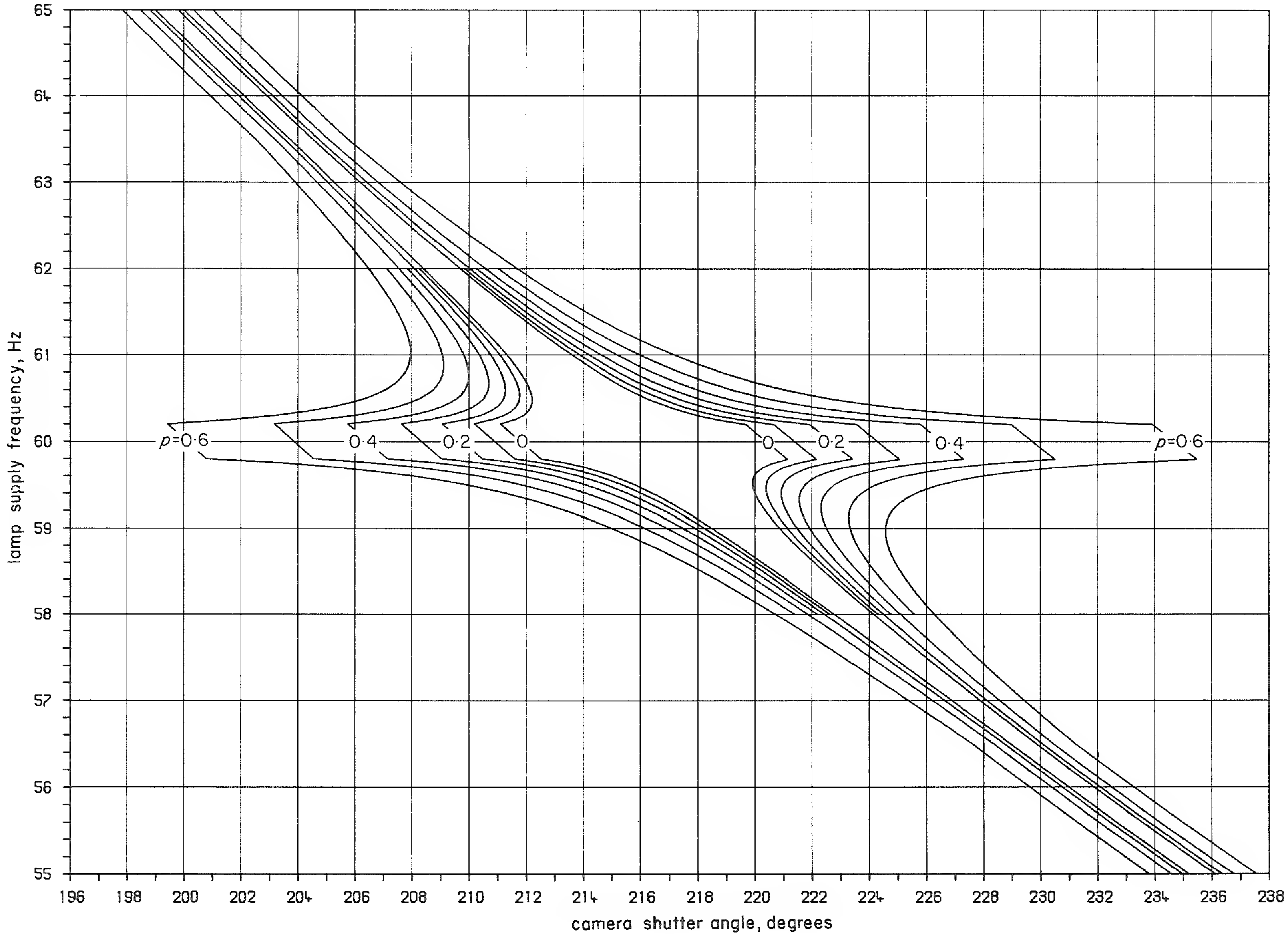

Chart 4 - Lamp supply frequency limits

$m = 5$ $N = 3$ camera frame frequency = 24 Hz (Ripple asymmetry limits : see chart 26)

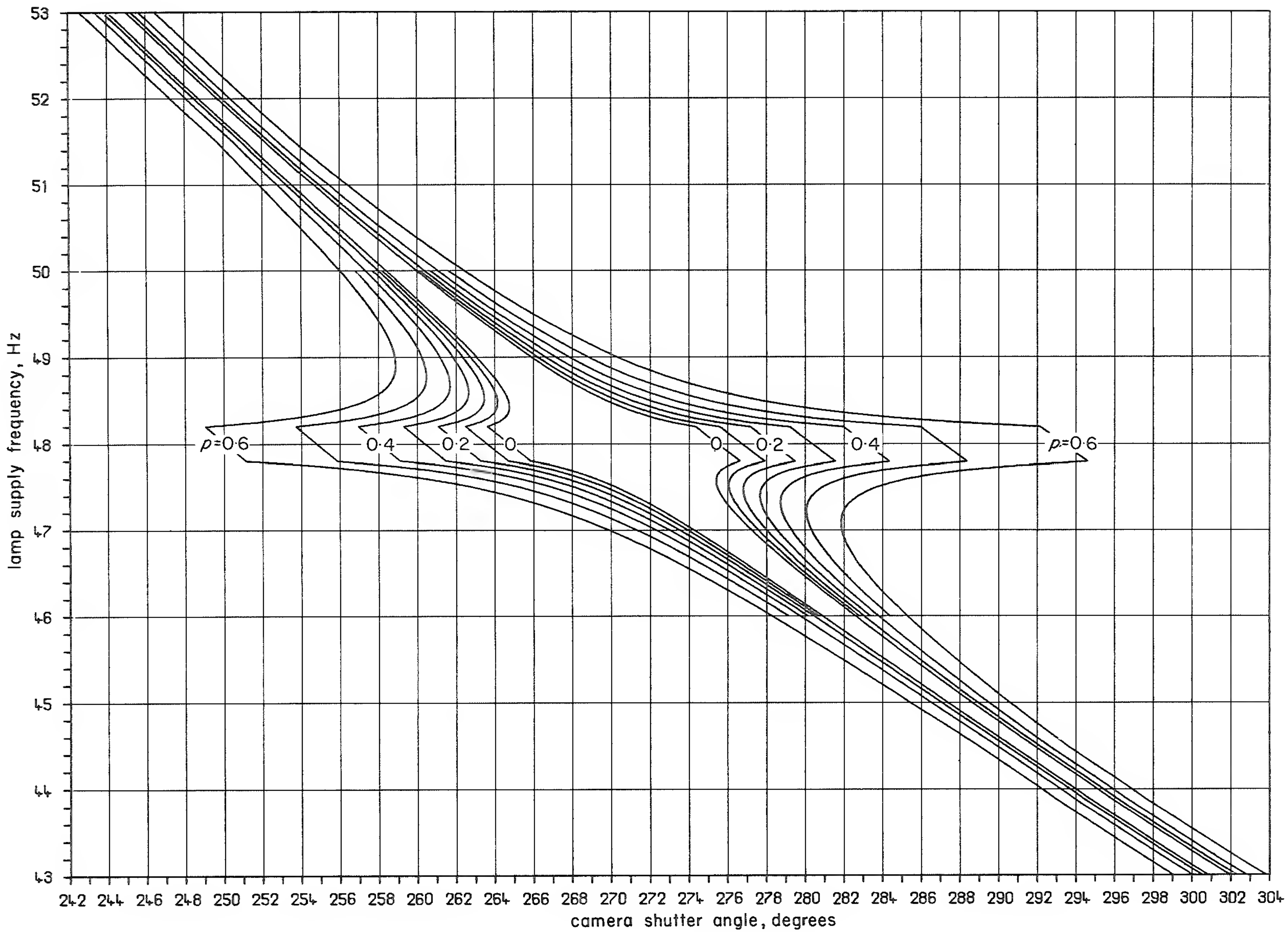

Chart 5 - Lamp supply frequency limits

$m = 4$ $N = 3$ camera frame frequency = 24 Hz (Ripple asymmetry limits : see chart 24)

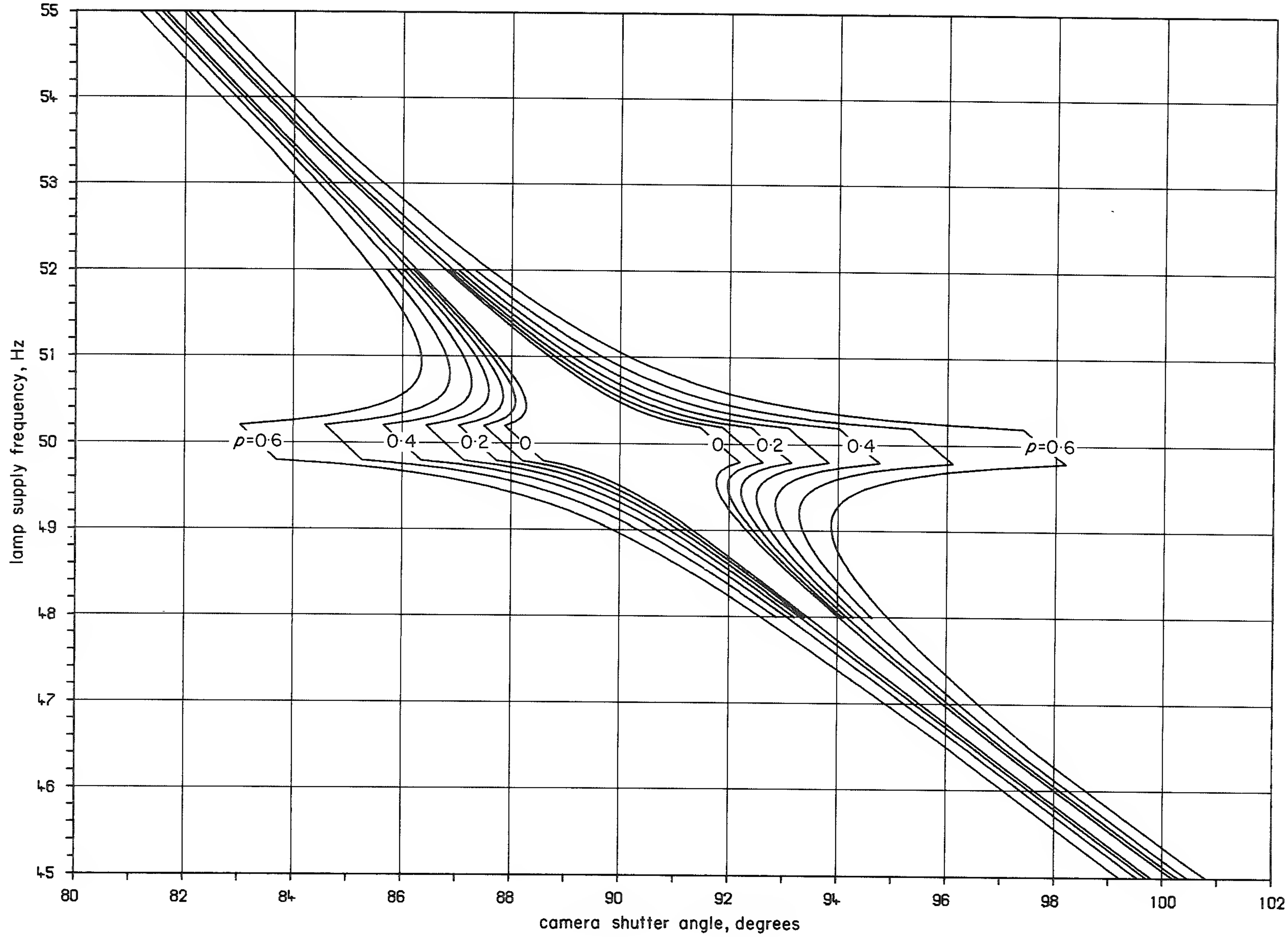

Chart 6 - Lamp supply frequency limits

$m = 4$ $N = 1$ camera frame frequency = 25 Hz (Ripple asymmetry limits : see chart 27)

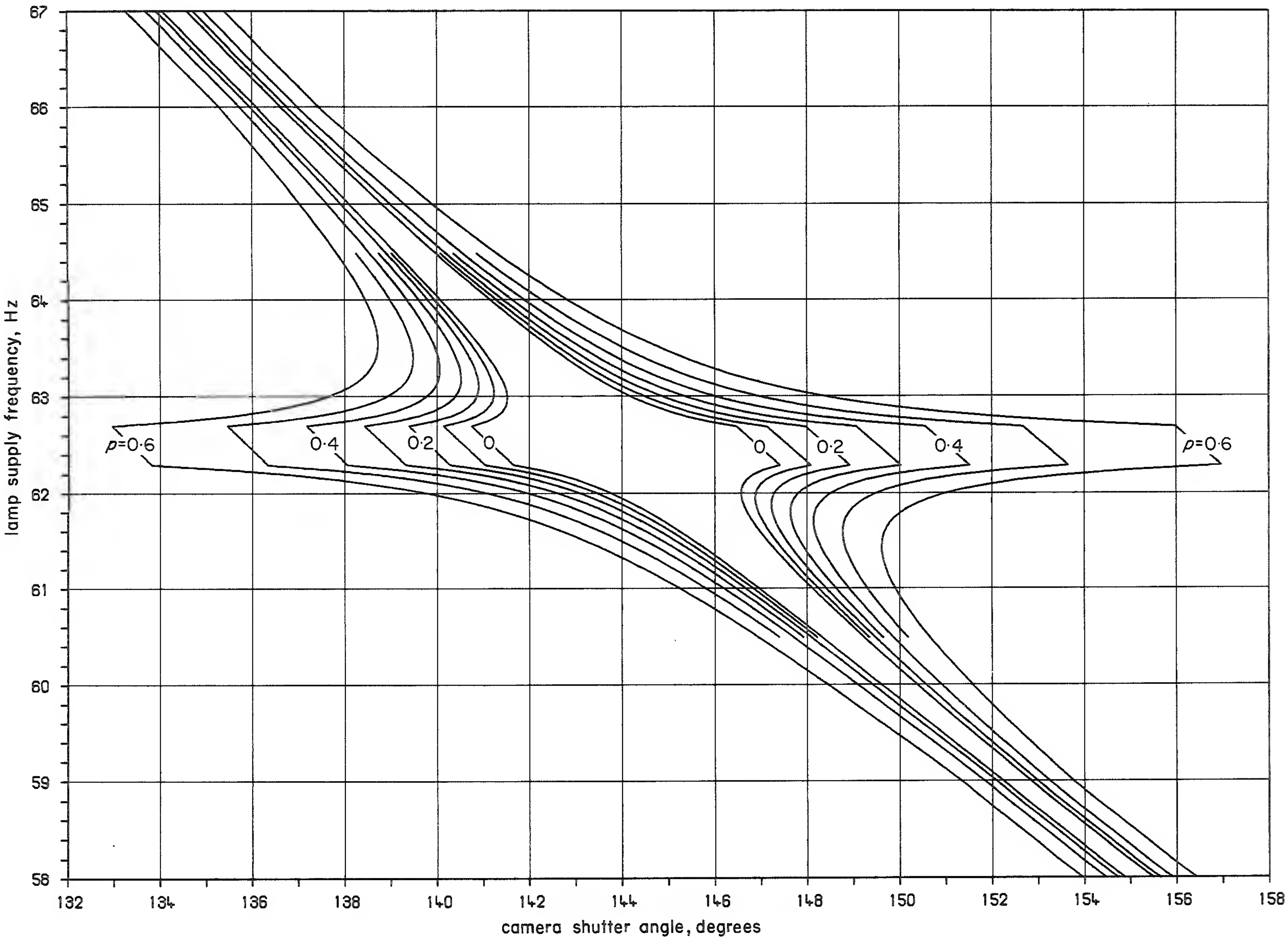

Chart 7 - Lamp supply frequency limits

$m = 5$ $N = 2$ camera frame frequency = 25 Hz (Ripple asymmetry limits : see chart 29)

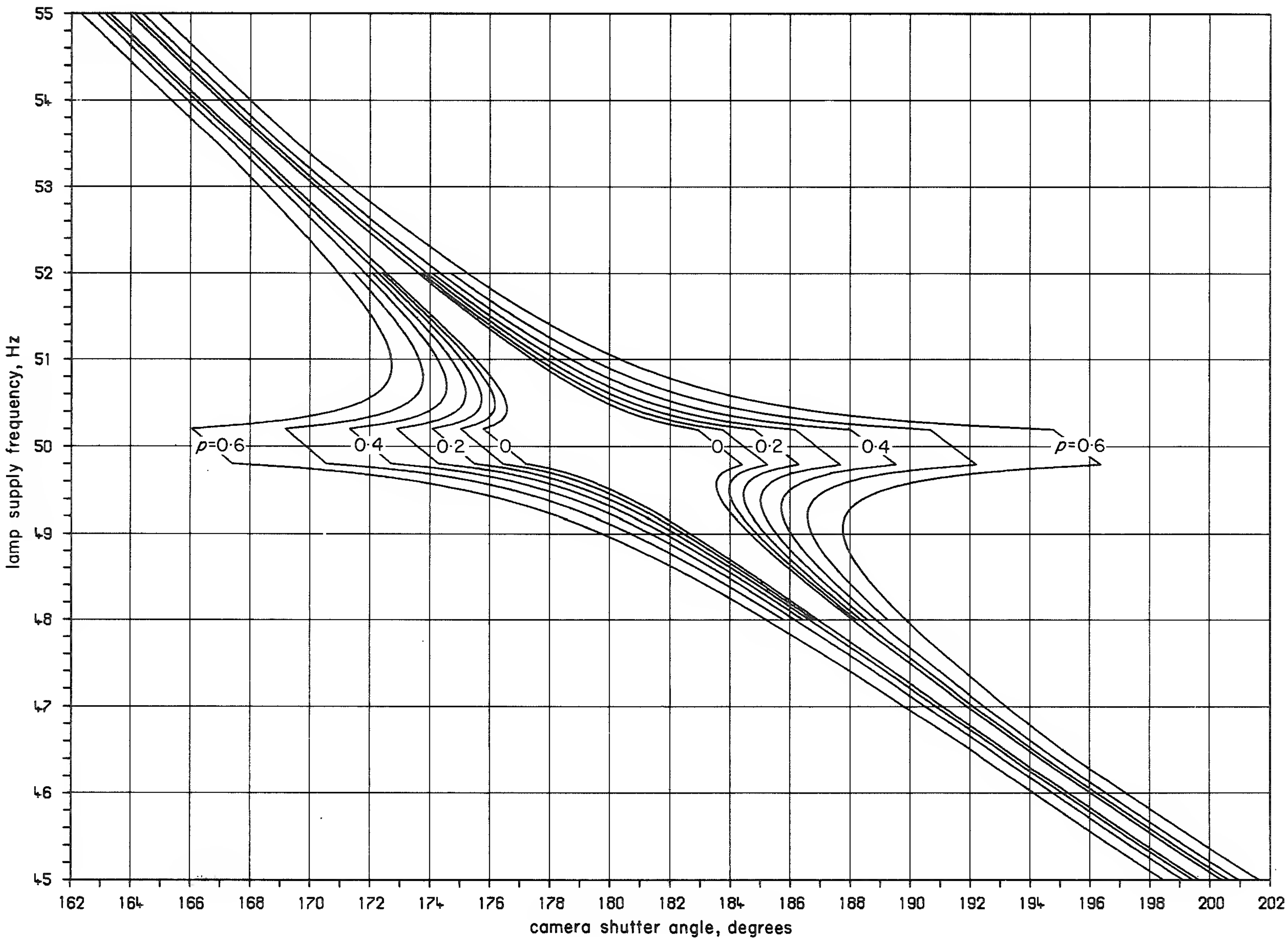

Chart 8 - Lamp supply frequency limits

$m = 4$ $N = 2$ camera frame frequency = 25 Hz (Ripple asymmetry not significant)

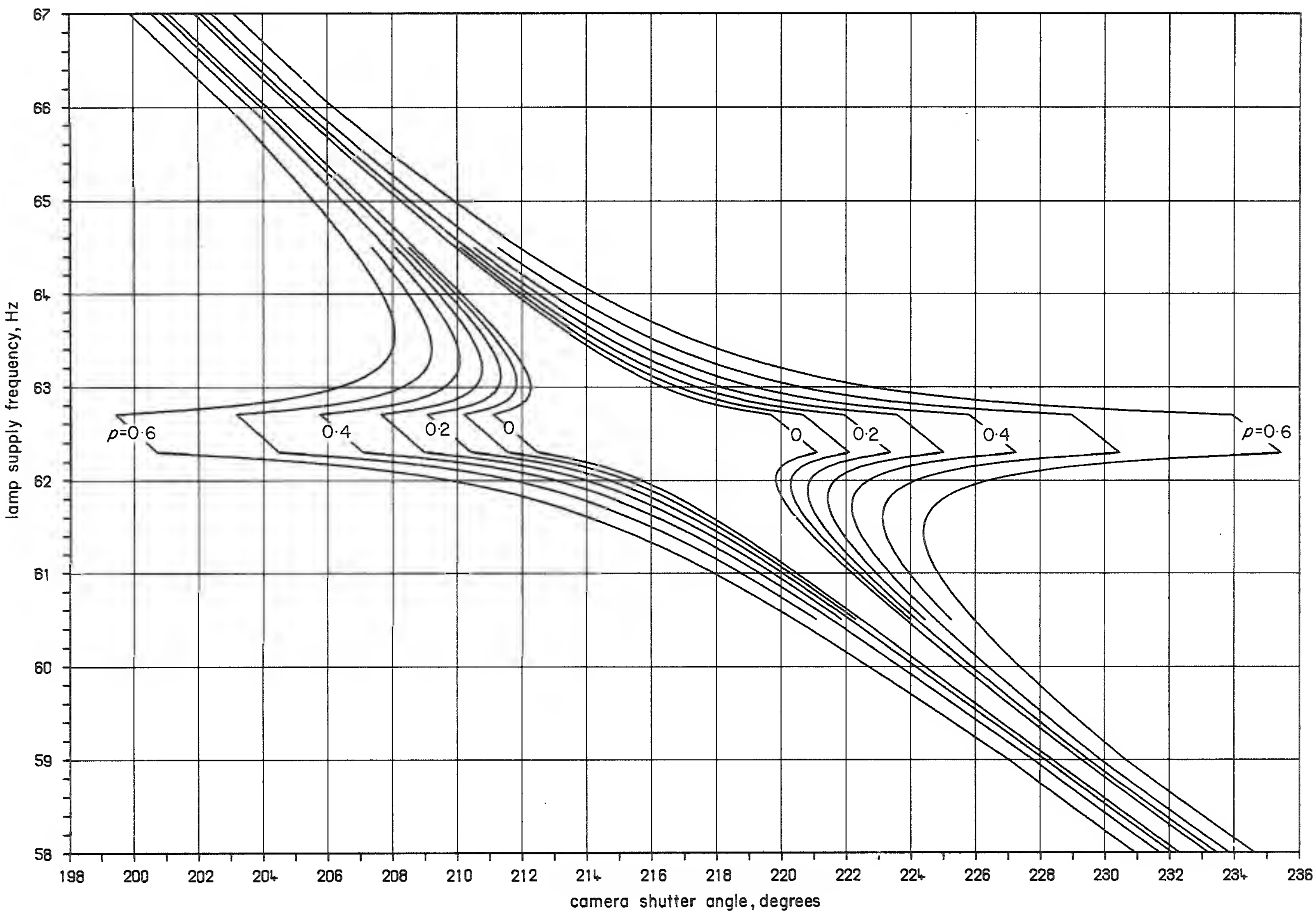

Chart 9 - Lamp supply frequency limits

$m = 5$ $N = 3$ camera frame frequency = 25 Hz (Ripple asymmetry limits : see chart 30)

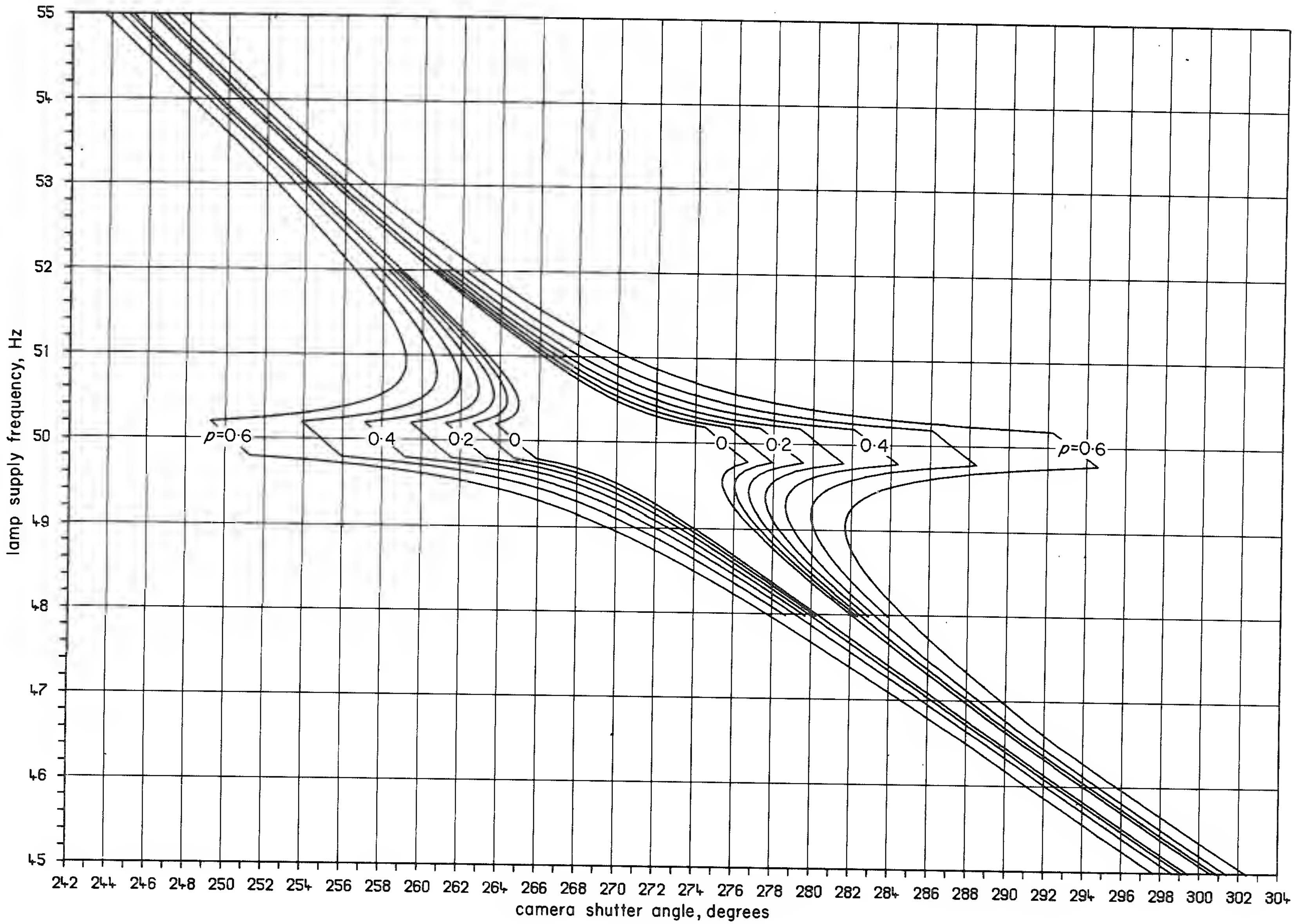

Chart 10 - Lamp supply frequency limits

$m = 4$ $N = 3$ camera frame frequency = 25 Hz (Ripple asymmetry limits : see chart 28)

3.3. Charts for two practical metal-halide lamps

The charts presented in this Section refer to the C.S.I. and H.M.I. metal-halide lamps (see Table 2). The method of use of these charts is as given in Section 3.2. The shutter angle range covered by these charts has been restricted and reference should be made to charts 1-10 for shutter angles between 83°-99° and 247°-299°. In the case of the C.S.I. lamp the outer contours refer to a ripple ratio of 0·4 (the manufacturers' quoted value) which is appropriate to well-diffused light from this lamp. There are, however, indications that p = 0·25 at the centre of the beam from a prefocussed unit and the short inner contours refer to this value. In the case of the H.M.I. lamp the contours shown are for a ripple ratio of 0·13. In saturated blue picture areas a reduction of ripple ratio to 0·06 may occur but the contour for this ripple ratio value is so close, over most of its length, to that for which p = 0·13 as to produce a negligible difference in the limiting safe lamp supply frequency values.

TABLE 2

Supply frequency limit charts for two practical metal-halide lamps

Chart No.	Lamp	Camera frame frequency (Hz)	Shutter angle range (degrees)
11	C.S.I.	24	134-156
12	C.S.I.	24	164-200
13	C.S.I.	24	201-234
14	C.S.I.	25	135-154
15	C.S.I.	25	165-199
16	C.S.I.	25	203-231
17	H.M.I.	24	134-156
18	H.M.I.	24	164-200
19	H.M.I.	24	200-235
20	H.M.I.	25	135-154
21	H.M.I.	25	164-199
22	H.M.I.	25	202-232

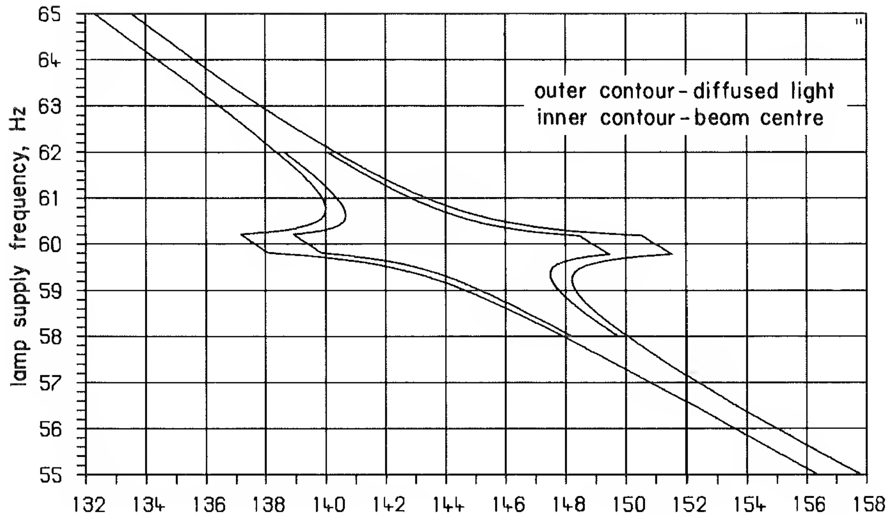

Chart 11

$m = 5$ $N = 2$
(Ripple asymmetry limits : see chart 25)

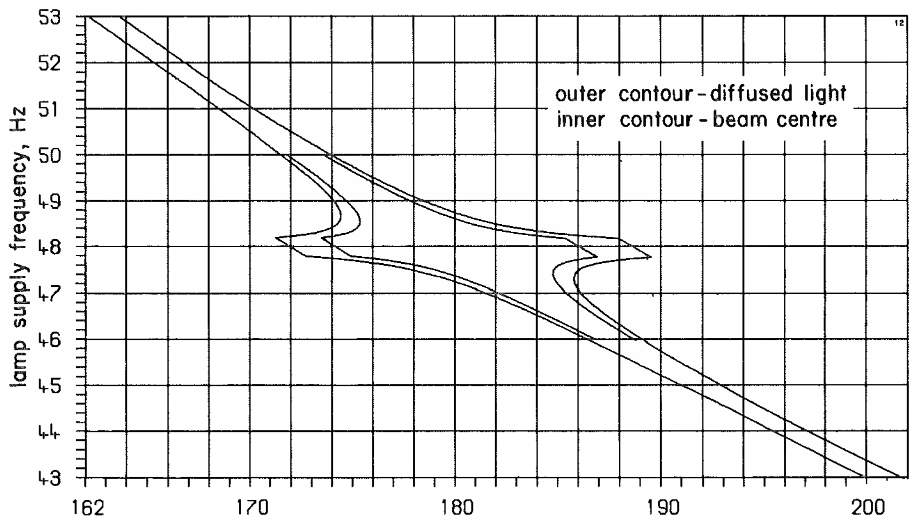

Chart 12

$m = 4$ $N = 2$
(Ripple asymmetry not significant)

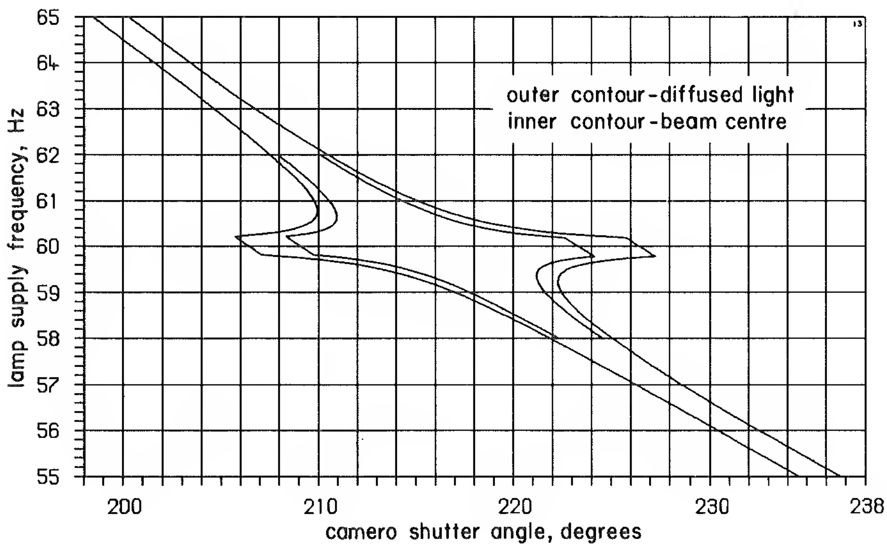

Chart 13

$m = 5$ $N = 3$
(Ripple asymmetry limits : see chart 26)

Charts 11—13 - Supply frequency limits for C.S.I. lamp
camera frame frequency = 24 Hz

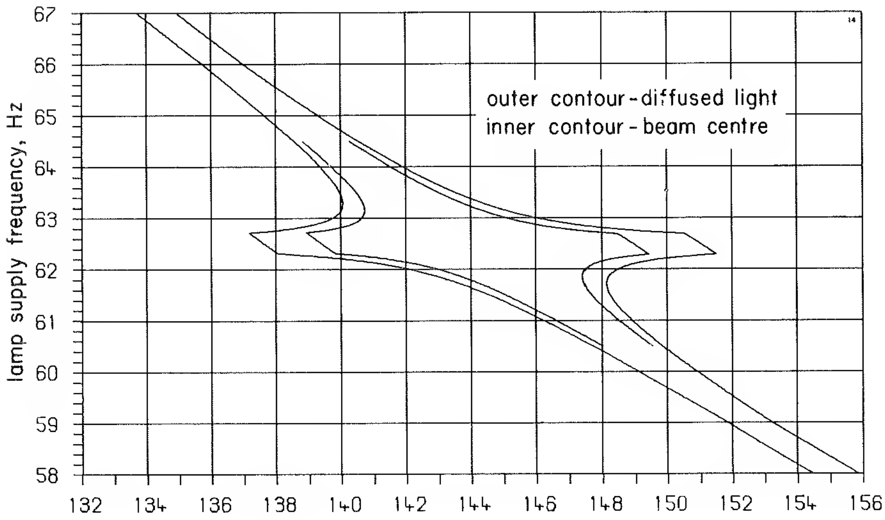

Chart 14

$m = 5$ $N = 2$
(Ripple asymmetry limits : see chart 29)

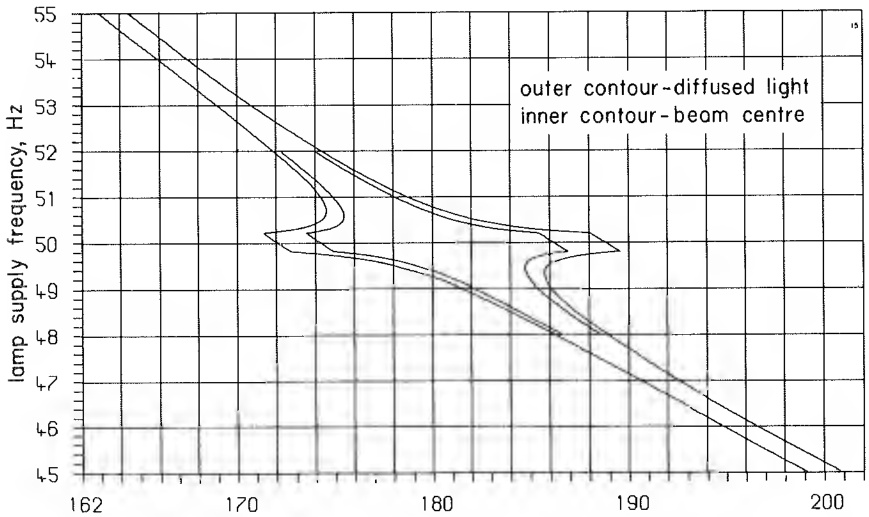

Chart 15

$m = 4$ $N = 2$
(Ripple asymmetry not significant)

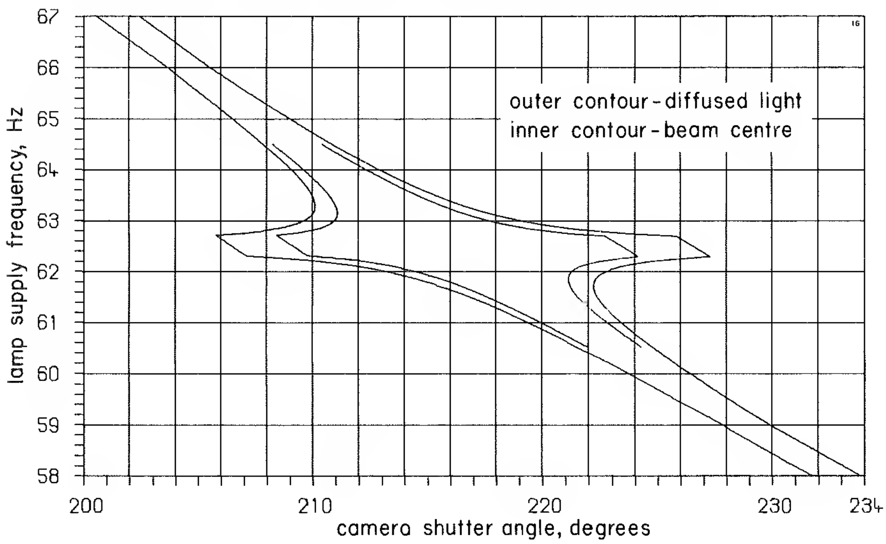

Chart 16

$m = 5$ $N = 3$
(Ripple asymmetry limits : see chart 30)

Charts 14—16 - Supply frequency limits for C.S.I. lamp
camera frame frequency = 25 Hz

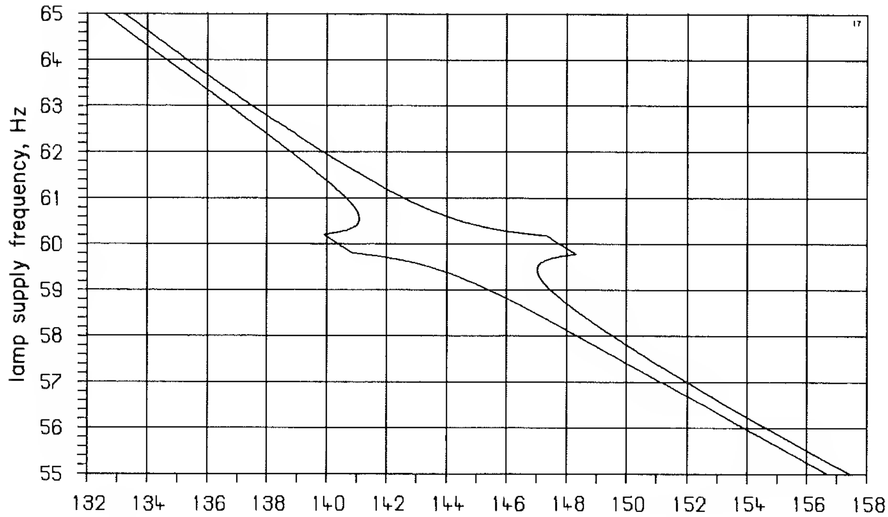

Chart 17

$m = 5$ $N = 2$
(Ripple asymmetry limits : see chart 25)

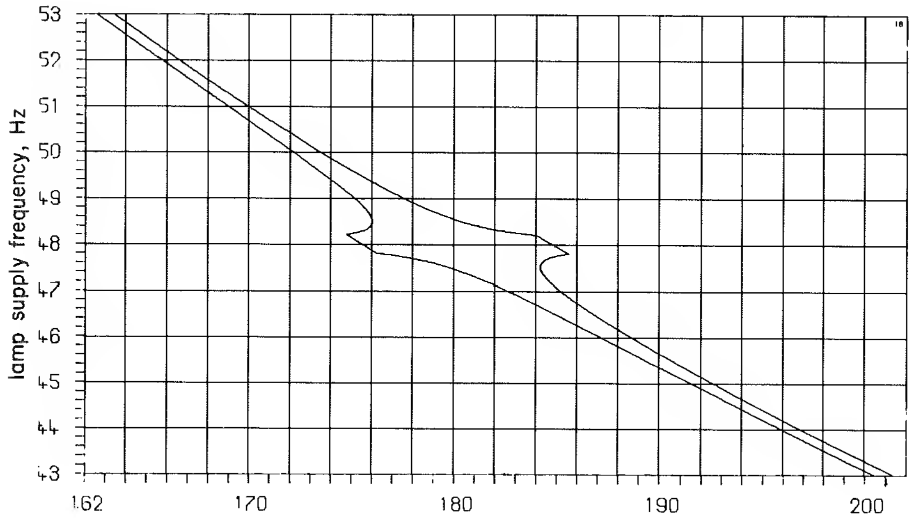

Chart 18

$m = 4$ $N = 2$
(Ripple asymmetry not significant)

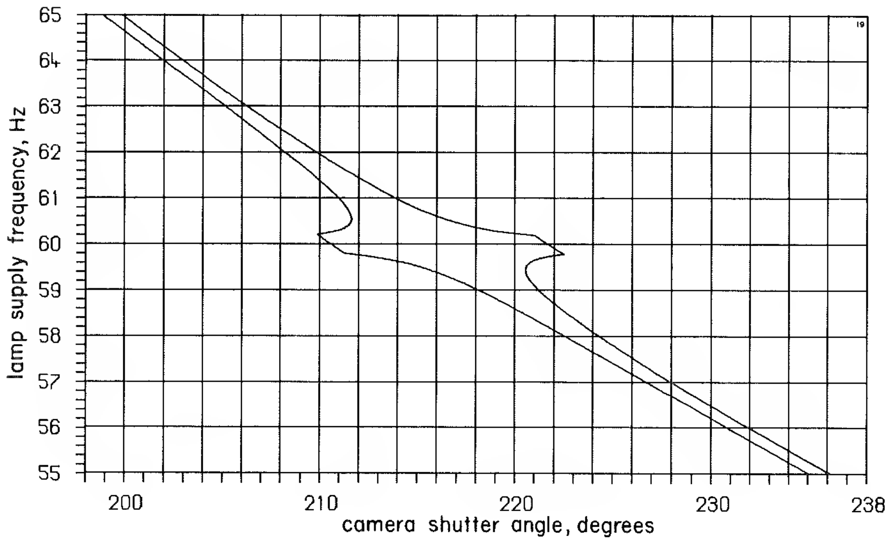

Chart 19

$m = 5$ $N = 3$
(Ripple asymmetry limits : see chart 26)

Charts 17–19 - Supply frequency limits for H.M.I. lamp
camera frame frequency = 24 Hz

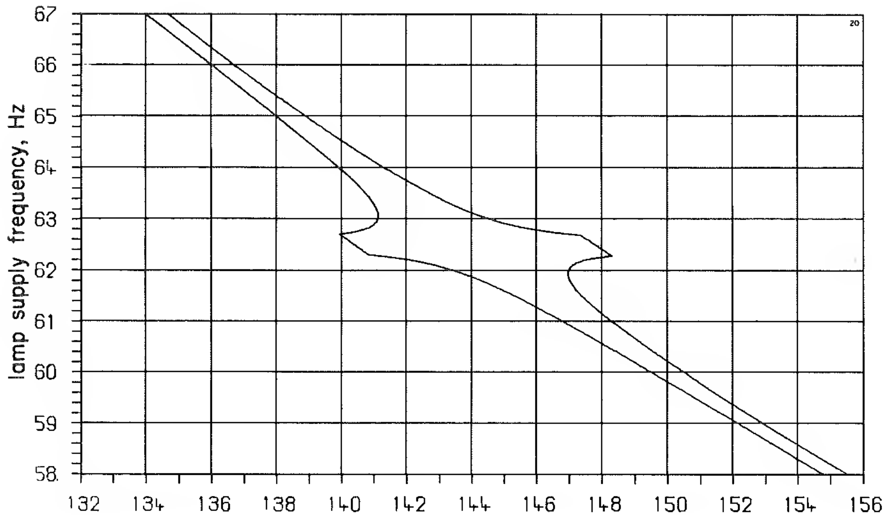

Chart 20

$m = 5$ $N = 2$
(Ripple asymmetry limits : see chart 29)

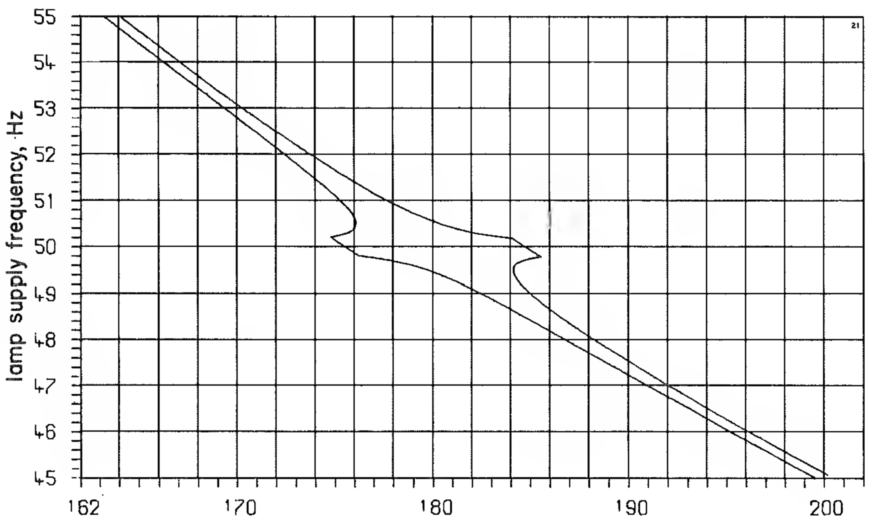

Chart 21

$m = 4$ $N = 2$
(Ripple asymmetry not significant)

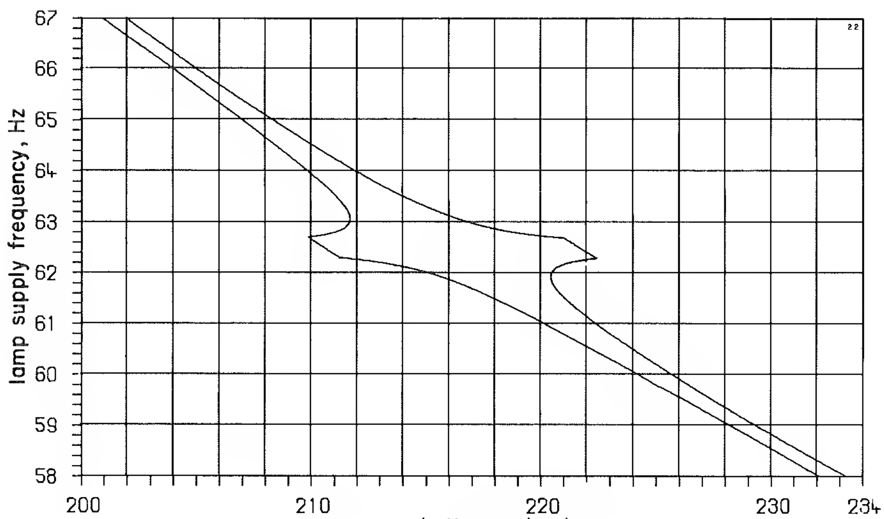

Chart 22

$m = 5$ $N = 3$
(Ripple asymmetry limits : see chart 30)

Charts 20–22 - Supply frequency limits for H.M.I. lamp

camera frame frequency = 25 Hz

3.4. A note on synchronous operation of camera and lamp supply

If the quantities $2f_s$ and mf_c in the right-hand side of Equations 9 and 10 are very nearly equal, the value of f_L will be very low and one cycle of picture luminance fluctuation will occupy a very long period. Under these conditions the visibility of the luminance fluctuations may be reduced to such an extent that exposure fluctuation ratios lower than the value of 28 dB shown in Fig. 2 may be permissible. If these two quantities are precisely equal then the value of f_L is precisely zero and the cycle of picture luminance fluctuation occupies "infinite" time: in other words, no picture luminance fluctuations occur. In this case there is theoretically no restriction on the relationships between the parameters which determine the magnitude of the exposure variation. However it must be noted that in this case the magnitude of exposure is a function of the phase relationship between the camera operating cycle and the lamp supply waveform. This has two consequences. In the first place, if the camera is stopped and restarted, this phase relationship may differ between the successive "takes", which may thus be differently exposed. In the second place, if the value of f_L is on average zero, but in fact varies about this average, this phase relationship will also change with time, giving rise to time-varying exposure variations which can cause perceptible picture luminance fluctuations. This situation can occur, for example, when the lamp is supplied from a mobile generator whose governor exhibits some "hunting" around the appropriate nominal frequency. The time variations of the resulting picture luminance fluctuations will in this case depend on the factors (e.g. the governor characteristics in this example) which determine the variation of the lamp supply frequency* about its mean value. For these reasons the technique of operating the camera in synchronism with the lamp supply, so as to permit filming under conditions which would otherwise give rise to perceptible picture luminance fluctuations, should only be used where both the camera frame frequency and the lamp supply frequency are very stable.

Ripple asymmetry is discussed in detail in Section 4, but its effect may be briefly noted in the present case of synchronous operation. Since, in this case, the frequency (f_L) of the principal luminance fluctuation component is zero, it can be seen from Equation 11 that the frequency (f'_L) of the asymmetry luminance fluctuation component will be at the maximum possible value of $f_p/2$ (i.e. alternate film frames receive greater or less exposure) when the value of the integer m in Equations 9 or 10 is odd. The amount of the asymmetry component of exposure variation that can be permitted is therefore reduced to a minimum (see Fig. 2) or, in other words, the effect of ripple asymmetry is enhanced to the fullest extent. This enhancement of the effect of ripple asymmetry, when m is odd, makes the reliance on synchronism between camera frame frequency and lamp supply frequency, to ensure freedom from picture luminance fluctuation effects, even more undesirable in the cases of lamp supply frequencies of 60 Hz and 62·5 Hz for camera frame frequencies of 24 Hz and 25 Hz respectively.

* This argument also applies if the camera frame frequency is unstable with time.

3.5. Operational relationships outside the range of charts 1-10

If lamp supply frequency tolerances are required for shutter angles not included in charts 1-10 (Section 3.2.) they may be derived from the formula

$$f_{s\pm} = \frac{180}{\theta} \cdot f_c \cdot N \left(1 \pm 0{\cdot}002 \frac{1+p}{1-p}\right) \qquad \ldots\ldots (18)$$

where f_{s+} and f_{s-} are the supply frequency limit values.

Note that, from Equations 3, 4 and 5, the value of N is given by the nearest integer to the quantity $(N + Q)$, where

$$(N+Q) = \frac{\theta}{180} \frac{f_s}{f_c} \qquad \ldots\ldots (19)$$

Equation 18 only applies where the frequency of the principal component of picture luminance fluctuation (f_L, Equation 10) is greater than 7 Hz, so that the limiting value of exposure fluctuation ratio (see Fig. 2) is 48 dB. This equation does not therefore apply in general to the conditions shown in charts 1-10 (Section 3.2.) and furthermore should not be used to attempt to derive data for the cases N = 1, m = 5 and N = 4, m = 5 (see Figs. 6 and 7) for which charts are not provided.

The effects of ripple asymmetry can be determined from charts 23-30 (Section 4.2.) using the supply frequency limits deduced from Equation 18.

4. The effect of ripple asymmetry

4.1. Discussion

Previous work[3] has shown that ripple asymmetry gives rise to components of picture luminance fluctuation in addition to the principal component produced by the intensity ripple itself. The effect of ripple asymmetry can be tested by the use of charts 23-30 in Section 4.2. The curves on the right-hand side of each of these charts enable an ordinate value to be deduced from values of asymmetry ratio (p', Equation 2) and ripple ratio (p, Equation 1). This ordinate value is related to the asymmetry exposure fluctuation ratio (R'_E: see Section 2.3.). The nature of this relationship [3b,3c] depends on whether the value of N (Equation 5) is odd or even. For odd values of N the ordinate value is simply the asymmetry exposure fluctuation ratio itself,[3d] while for even values of N the ordinate value is the ratio of the asymmetry and principal exposure fluctuation ratios.[3e] Fortunately it has been possible to construct charts 23-30 in such a

way that no account need be taken of the precise nature of this relationship* when using them, except to note that the relationships for both odd and even values of N are independent of the value of Q (see Equation 5) and that these charts therefore apply for all camera shutter angles. The left-hand side of each of the charts is based on Fig. 2 and shows the limiting value of exposure fluctuation ratio, in terms of the appropriate ordinate relationship as discussed above, and scaled in terms of the lamp supply frequency rather than the luminance fluctuation frequency (see Equations 10 and 11).** Thus the charts may be used to test whether or not luminance fluctuations due to the asymmetry exposure variation component will be perceptible, assuming that charts 1-10 (Section 3.2.) indicate imperceptibility of the principal luminance fluctuation component.

Although the ripple ratio for a particular lamp is fixed once the operating parameters have been chosen, it has been found that the same consistency is not obtained in the case of the asymmetry ratio, and that the asymmetry ratio value (p') can change randomly with time. This effect has not been studied in detail, but limited experience has shown that while values of p' below 0·95 do not frequently occur, values of p' in the region of 0·98 may not be unusual. In the absence of more precise information on this subject, these values of p' may be of use in determining the likely effect of ripple asymmetry from charts 23-30.

4.2. Ripple asymmetry charts

The derivation and use of these charts has been described in detail in Section 4.1. A summary of the method of use of the charts follows:—

1) Select the appropriate chart for the required camera frame frequency and values of N and m, as shown in the chart used to determine the safe lamp supply-frequency limits (see Table 3).***

2) Select the appropriate curve in the right-hand portion of the chart for the required ripple ratio, interpolating between the curves shown on the chart if necessary.

3) Draw a vertical line from the appropriate value of asymmetry ratio (shown along the horizontal axis in the right-hand portion of the chart) to intersect this curve, and draw a horizontal line from this point of intersection to extend into the left-hand portion of the chart. If this vertical line extends to the upper boundary of the chart without intersecting the curve selected in step 2, luminance fluctuation effects due to the presence of ripple asymmetry will not be visible and steps 4 and 5 below may be omitted.

4) Draw a vertical line from the appropriate value of lamp supply frequency (shown along the horizontal axis in the left-hand portion of the chart) to intersect the horizontal line drawn in step 3.

5) If the point of intersection in step 4 is in the unshaded area of the left-hand portion of the chart, picture luminance fluctuations due to the presence of ripple asymmetry should not be visible, provided that conditions are such that luminance fluctuations due to the ripple component itself are imperceptible.

TABLE 3

Ripple asymmetry limit charts

Chart No.	Camera frame frequency (Hz)	N	m
23	24	1	4
24	24	3	4
25	24	2	5
26	24	3	5
27	25	1	4
28	25	3	4
29	25	2	5
30	25	3	5

* For this reason the ordinate axis is uncalibrated, as numerical values along this axis are irrelevant when using the charts.

** This simplifies the use of the charts but doubles their number as separate charts are required for camera frame frequencies of 24 Hz and 25 Hz.

***No chart is provided for N = 2, m = 4, since in this case luminance fluctuations due to the asymmetry exposure variation component are always less perceptible than those due to the principal component.

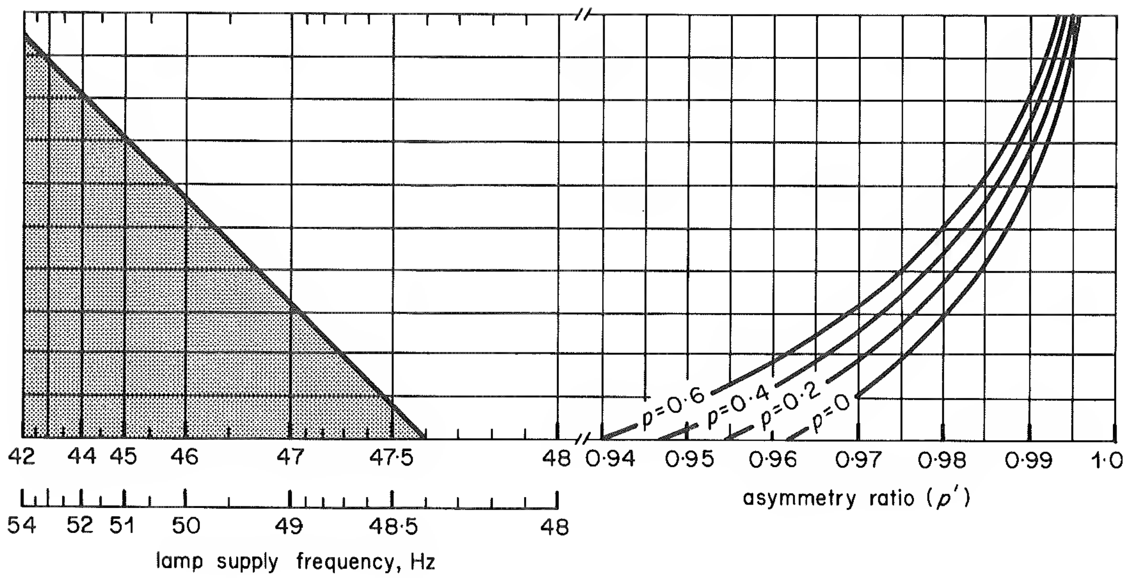

Chart 23 - Ripple asymmetry limits

$m = 4$ $N = 1$
camera frame frequency = 24 Hz

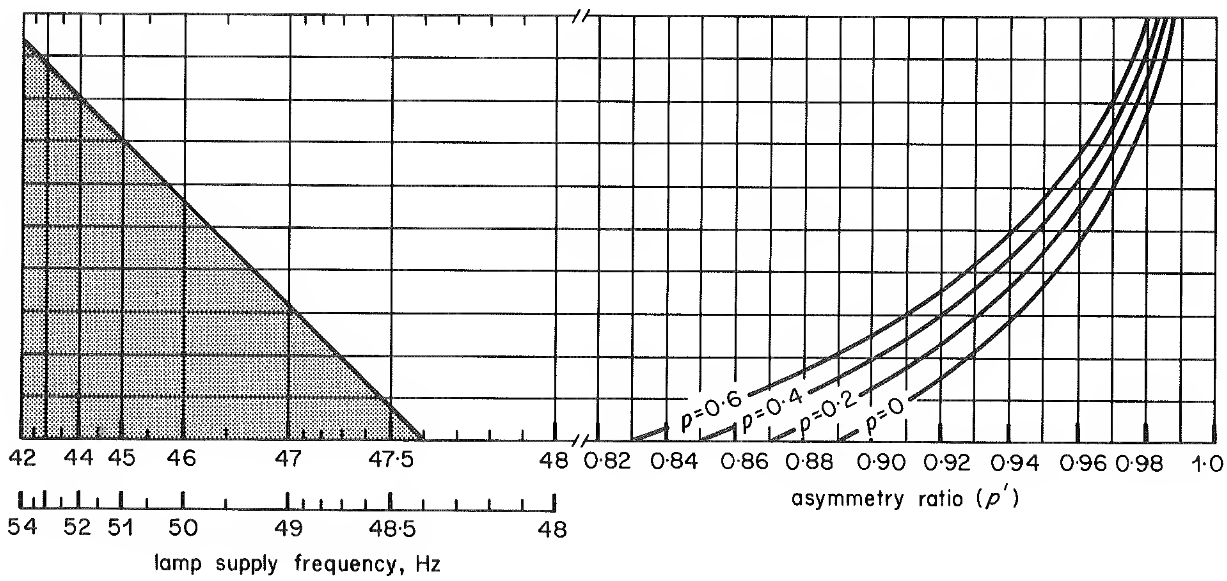

Chart 24 - Ripple asymmetry limits

$m = 4$ $N = 3$
camera frame frequency = 24 Hz

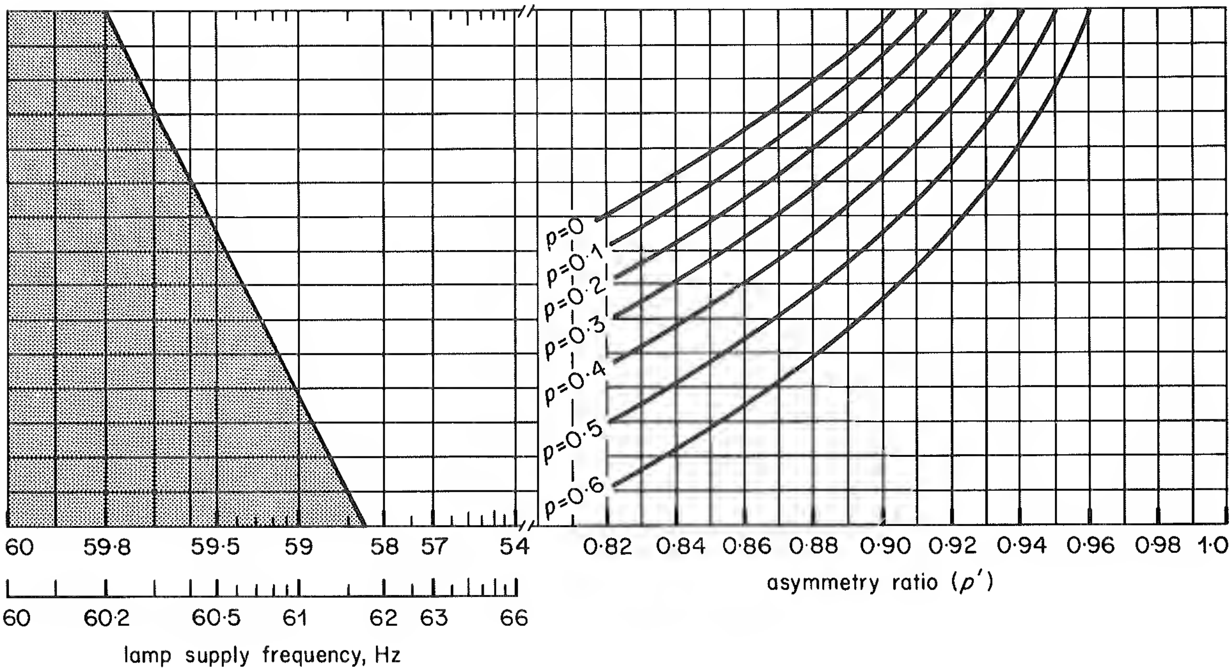

Chart 25 - Ripple asymmetry limits

$m = 5 \qquad N = 2$
camera frame frequency = 24 Hz

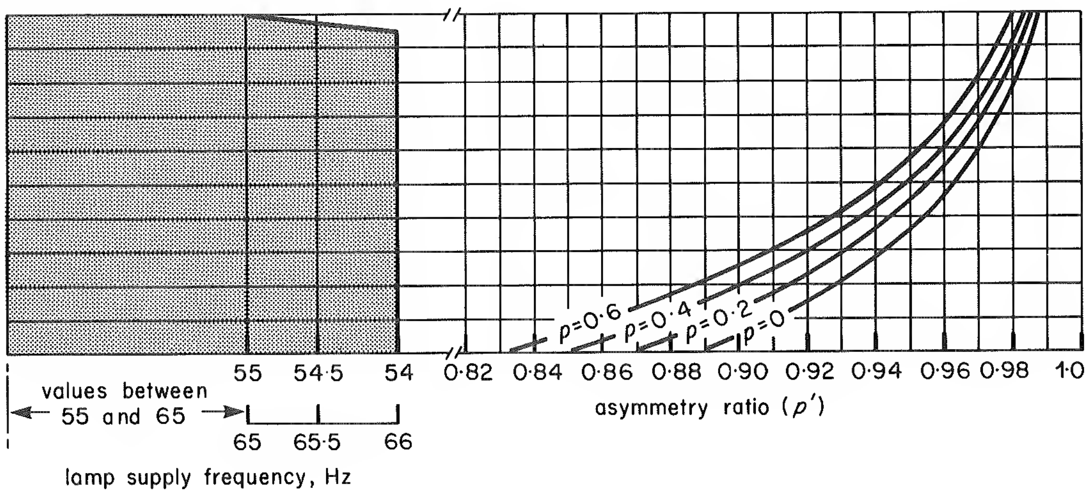

Chart 26 - Ripple asymmetry limits

$m = 5 \qquad N = 3$
camera frame frequency = 24 Hz

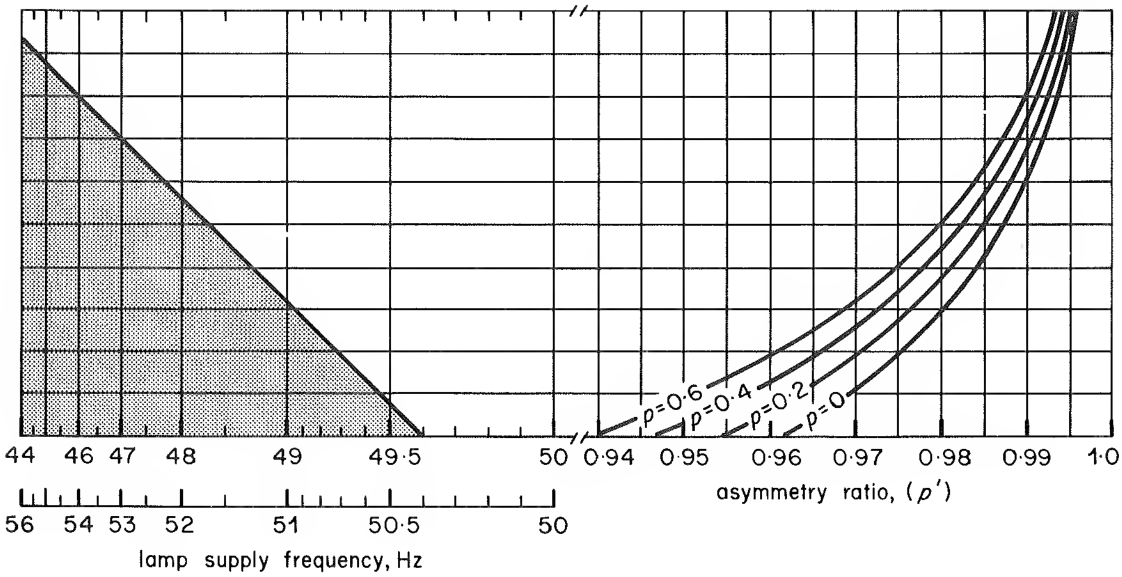

Chart 27 - Ripple asymmetry limits

$m = 4$ $N = 1$
camera frame frequency = 25 Hz

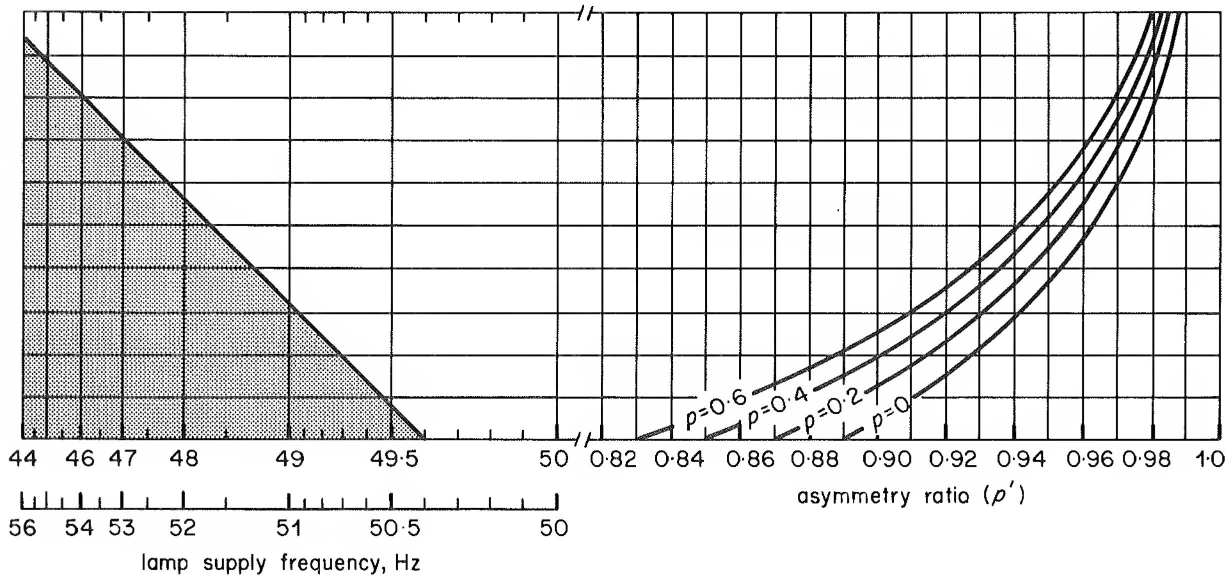

Chart 28 - Ripple asymmetry limits

$m = 4$ $N = 3$
camera frame frequency = 25 Hz

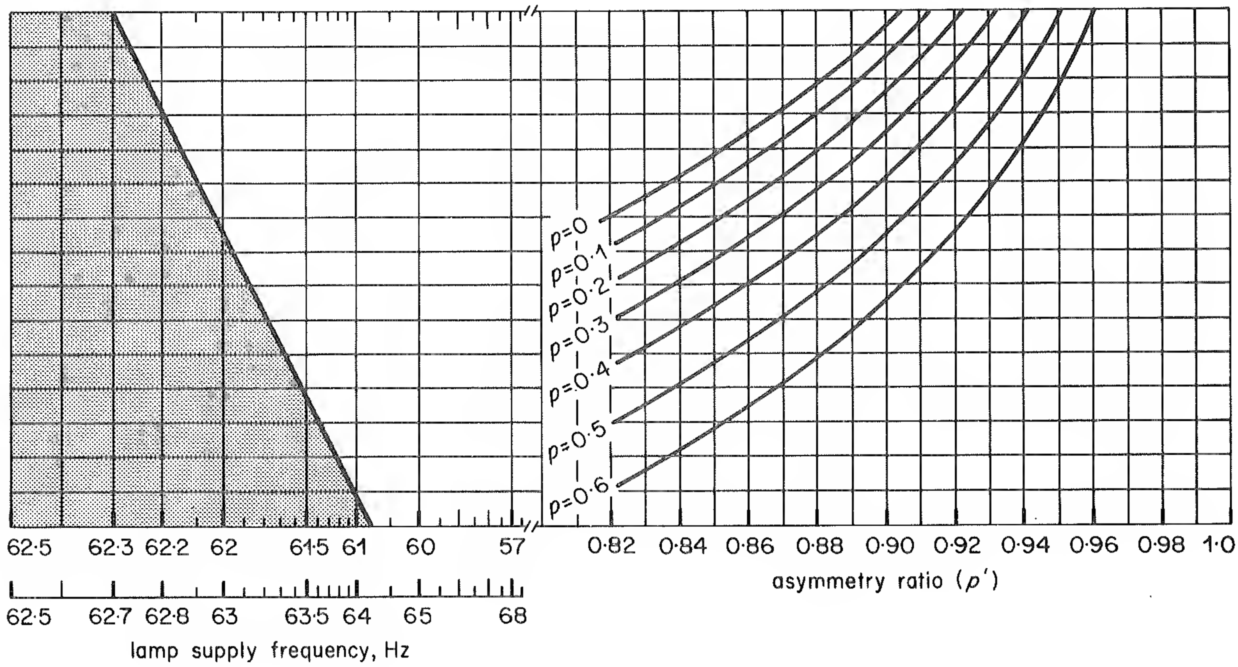

Chart 29 - Ripple asymmetry limits

$m = 5$ $N = 2$

camera frame frequency = 25 Hz

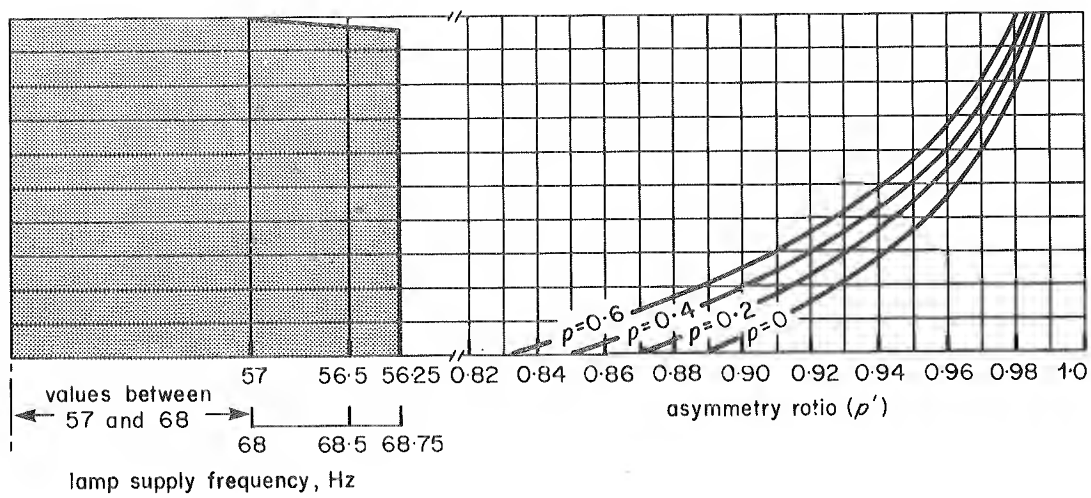

Chart 30 - Ripple asymmetry limits

$m = 5$ $N = 3$

camera frame frequency = 25 Hz

5. Conclusions

Charts have been constructed which enable safe lamp supply frequencies to be found for a wide range of shutter angles (or, conversely, to indicate suitable shutter angles for given lamp supply frequencies), so that perceptible picture luminance fluctuations may be avoided when using discharge lamps for film lighting.

Charts are also provided for the assessment of the effect of asymmetry of the alternating "ripple" component of the light from such lamps. It is noted that the importance of this asymmetry is markedly dependent on the precise conditions of operation of the lamp and film camera.

6. References

1. TAYLOR, E.W. On the visibility of luminance fluctuations in television pictures, and exposure variations in motion picture film. B.B.C. Research Department Report No. 1975/13.

   1a Ibid: Fig. 16.

2. TAYLOR, E.W. Some aspects of the use of metal-halide discharge lamps for film lighting. B.B.C. Research Department Report No. 1976/2.

   2a Ibid: p.13.
   2b Ibid: Equation 7
   2c Ibid: Appendix
   2d Ibid: Section 3.3.

3. TAYLOR, E.W. Film lighting using metal-halide lamps: the effect of ripple asymmetry. B.B.C. Research Department Report No. 1977/8.

   3a Ibid: Section 6.1.
   3b Ibid: Section 5.2.
   3c Ibid: Section 5.3.
   3d Ibid: Section 6.4.
   3e Ibid: Section 6.3.

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